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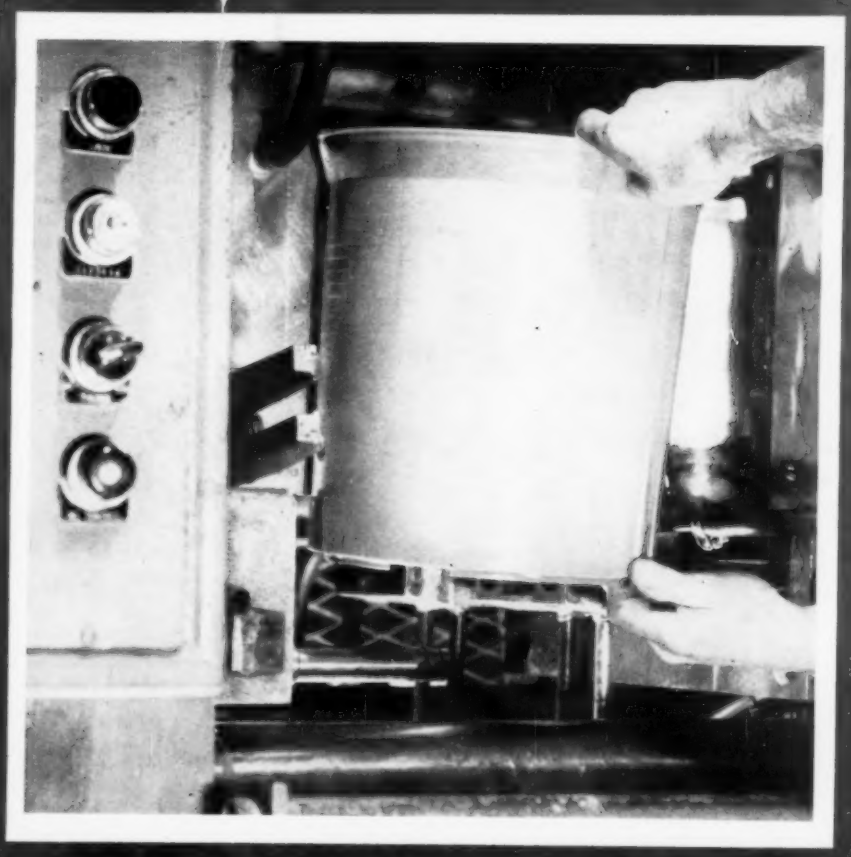
PLASTICS ENGINEERS JOURNAL



HIGH DENSITY POLYETHYLENE REFUSE CAN MOLDED AT 78 PER HOUR

(See page 7)

OCT., 1958 VOLUME 14, NUMBER 8

Hospitals will welcome this new lightweight sterilizer tray made of heat-resistant MARLEX . . . withstands sterilizer temperatures up to 250° F. for *hours!*

MARLEX tote boxes filled with chickens moving into this quick-freezer easily withstand repeated freezing and steam cleaning, as well as the usual severe production-line handling.

The best tote boxes are made of MARLEX*

RIGID POLYETHYLENE

. . . lightweight, unbreakable, low in cost!

"We picked Marlex because it has what it takes to deliver satisfactory service in restaurants, cafeterias, hotels, hospitals, and the institutional food field," says Daniel Bloomfield of Bloomfield Industries, 4546 West 47th Street, Chicago 32, Ill.

"Here is a tough, rugged plastic that is completely sanitary," Mr. Bloomfield points out. "You can put our new Marlex All-Purpose Dish Boxes and Silverware Trays through commercial cleansing procedures.

"Marlex doesn't stain from oils, fats or greases. It won't dent, either. So this equipment keeps its good looks. And the price is right."

Injection-molded restaurant equipment is just one of many profitable applications for Marlex polyethylene.

No other type of material can serve so well and so economically in so many different uses.

For more information, get in touch with your local Marlex sales representative.

*MARLEX is a trademark for Phillips family of olefin polymers.

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Bartlesville, Oklahoma
A subsidiary of Phillips Petroleum Company

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Here's your answer to rising costs

HOW D-M-E STANDARD MOLD BASES CAN KEEP YOUR MOLD COSTS DOWN DESPITE RISING COSTS OF STEEL, LABOR AND TOOLS

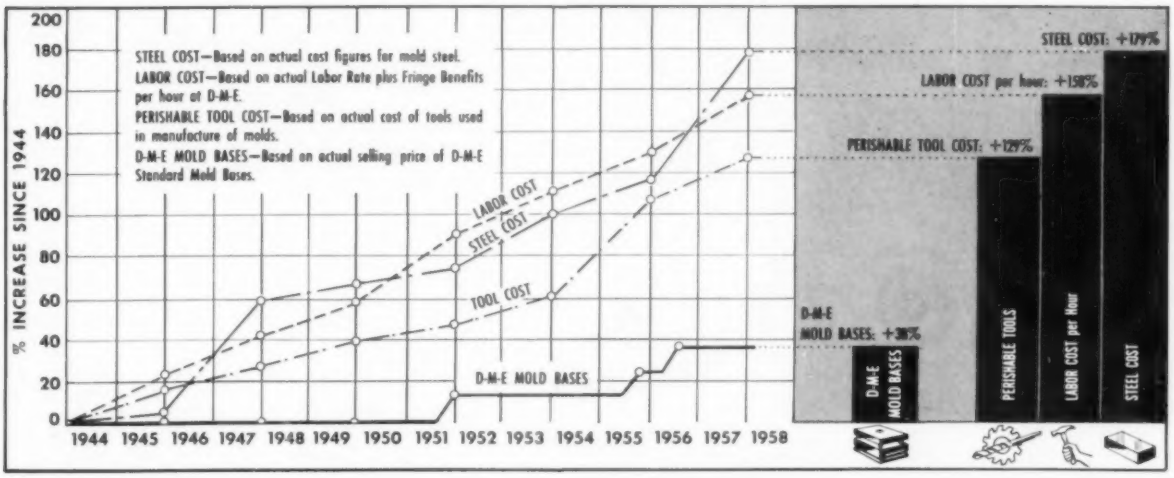
Whether to make or buy an industrial product is one of the most important decisions any manufacturer continually faces. To accurately judge the economy in D-M-E Mold Base standardization, basic cost factors were analyzed dating back to the origin of Standard Mold Bases by D-M-E over 15 years ago. The analysis is plotted on the graph shown below. How these factors affect the cost of the mold is what makes the important difference in whether to make or buy Standard Mold Bases.

Since 1944, the cost of steel has increased 179%; the hourly cost of labor has climbed 158% and the cost of perishable tools has gone up 129%! In the same period the net selling price of D-M-E Standard Mold Bases has increased only a fraction of these amounts.

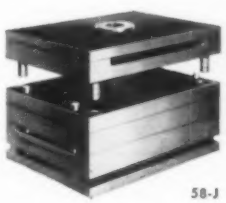
For the mold builder making his own mold bases throughout this period, rising steel, labor and tool costs are reflected in the increased cost of his own finished molds. The savings to the mold builder who long ago recognized the advantages of Standard Mold Bases, become immediately obvious.

The company using D-M-E Standard Mold Bases today not only saves money NOW, but can rely on a more stable cost factor for anticipated mold building programs. At the same time investment capital is freed for equipment more suited to special requirements.

Why it costs less to buy D-M-E standard mold bases than it does to make your own



WRITE FOR the April issue of the D-M-E News giving complete details on "How to reduce mold costs". Or contact your nearest D-M-E Branch for the 170 page Catalog of Standard Mold Bases and Moldmakers' Supplies. Start saving Now!



58-J

DME **DETROIT MOLD ENGINEERING COMPANY**

Contact Your Nearest Branch For Faster Deliveries!

- DETROIT: 6686 E. McNichols Rd.—CHICAGO: 5901 W. Division St. HILLSIDE, N.J.: 1217 Central Ave.—LOS ANGELES: 3700 S. Main St.
- D-M-E CORP., CLEVELAND: 502 Brookpark Rd.—DAYTON: 550 Leo St.
- D-M-E of CANADA, TORONTO, ONT.: 156 Norseman Ave.

A SUPERIOR

specifically designed for

IMPACT STRENGTH *and* **STYLE**

BAKELITE
BRAND

TGD-6000 STYRENE

This high-impact, rubber-modified extrusion compound is the result of a development program to provide extruders and vacuum formers with preferred features: strength, eye appeal and durability.

In addition this improved BAKELITE Brand Styrene extrudes at faster rates—has exceptionally high elongation values—possesses permanent high gloss and excellent rigidity. TGD-6000 Styrene is available in a wide variety of colors that retain stability even under heat polishing.

Write Dept. SJ-28 for Technical Release #15 giving complete fabrication details.

TGD-6000 is particularly suited for use in refrigerator door liners for two important reasons: 1. *lustrous appearance and smooth surface* for eye appeal and ease of cleaning; 2. *high* impact strength, even at subnormal temperatures. TGD-6000 permits the use of thinner sections.

SUPERIOR EXTRUDABILITY

TGD-6000 is capable of fast extrusion, with high quality, on conventional equipment.

RECOMMENDED EXTRUSION CONDITIONS

Screen pack	20/60/80 mesh
All cylinders	350-400 deg. F.
Head temperature	400 deg. F.
Die temperature	420 deg. F.
Feed end	Cold water
Screw temperature	Neutral
Compound temperature at discharge	410-425 deg. F.

B-2028

STYRENE

TYPICAL PROPERTIES

Values Relating to Fabrication

Extrusion Compound Temp. at Die, deg. F.	400-425
Specific Gravity (D792-50)	1.04

Values from Mechanical Tests*

Izod Impact Strength (D256-56), ft-lb/in. of notch	1.0
Tensile Strength (D638-56T) psi	3400
Elongation in Tension (D638-56T), per cent	30
Flexural Strength (D790-49T), psi	8000
Modulus of Elasticity in Flexure (D790-49T), psi	370,000

Values from Miscellaneous Tests*

Thermal Coefficient of Linear Expansion (D696-44) per deg. C.	8×10^{-5}
Water Absorption (D570-54T), per cent gain in weight in 24 hours	0.12
Durometer Hardness (D676-55T), D Scale	80

*Values obtained from extruded sheet 0.100 in. thick

EASIER VACUUM FORMING

Because TGD-6000 possesses such excellent strength and elongation properties, sheets may be formed and deep drawn in highly detailed designs—without cracking, breaking or warping at corners. High gloss surface is maintained during deep-draw vacuum forming.

TGD-6000 affords extruders and vacuum formers design and production advantages to expand their facilities to include a broader range of specialized applications and new products. Suggested other uses include displays, signs, toys, television masks, appliance housings, guards and novelties.

BAKELITE BRAND **PLASTICS**

Products of UNION CARBIDE *Corporation*

BAKELITE COMPANY, *Division of Union Carbide Corporation,* 30 East 42nd Street, New York 17, N. Y.
The terms BAKELITE and UNION CARBIDE are registered trade-marks of UCC.

MAY
1958

DOW

Plastiatrics

DOW'S CLINICAL APPROACH TO HEALTHY PLASTICS APPLICATION

MOLDING CHARACTERISTICS OF POLYETHYLENE AND POLYSTYRENE STUDIED

NEW STUDY AIMED AT REDUCING COMPLEXITY OF MATERIAL SELECTION FOR HOT RUNNER AND RUNNERLESS MOLDING

Careful selection of the materials to be used for hot runner and runnerless molding is extremely important. Both polyethylene and polystyrene exhibit characteristics which are desirable, and various formulations of both materials are widely used for hot runner and runnerless molding. To help plastics fabricators select the right material, Dow Plastics Technical Service Engineers have conducted a series of exhaustive tests on polyethylene and polystyrene and have arrived at the following list of properties which might be desirable for this type of molding:

1. Temperature sensitivity and easy flow at low temperatures.
2. Pressure sensitivity and easy flow at low temperatures.
3. High heat distortion temperature, thus permitting quicker ejection from the mold.
4. A high rate of thermal conductivity to remove the heat rapidly from the material.
5. Low specific heat, thus requiring less time to solidify.

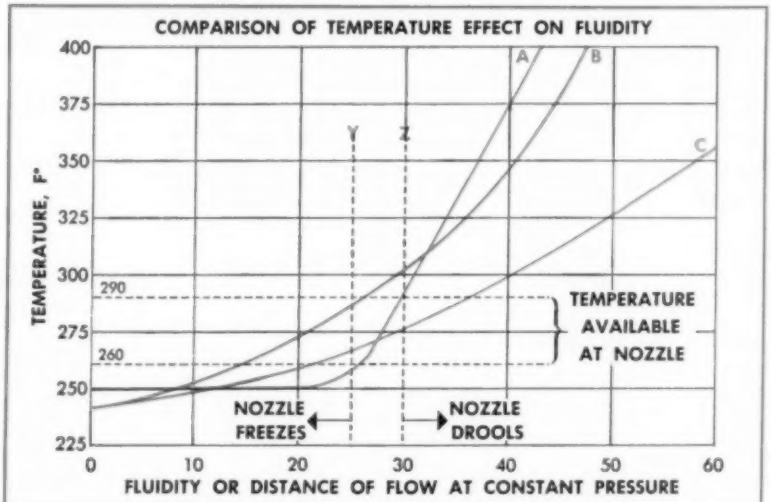
These characteristics are summarized in the chart illustrated at right.

AMERICA'S FIRST FAMILY OF POLYSTYRENES

GENERAL PURPOSE
- STYRON® 666
- STYRON 666M (Easy Flow)
- STYRON 665 (Extrusion)
- STYRON 689 (Easy Flow)

HIGH IMPACT
- STYRON 475
- STYRON 475M (Easy Flow)
- STYRON 777 (Medium Impact)
- STYRON 440 (Heat Resistant)
- STYRON 440M (Easy Flow)
- STYRON 480 (Extra-High Impact)

HEAT RESISTANT
- STYRON 683
- STYRON 700



The materials shown, A, B & C, have approximately the same heat distortion temperature. All molding conditions except temperature are held constant. The material in the nozzle must have enough fluidity to flow under the given pressure of 16,000 psi, as indicated by the vertical line Y. A material having fluidity greater than 25 but less than 30 will flow under pressure and will not drool as pressure is released. If the fluidity is greater than 30, drooling will occur.

Material A has a wide softening range and becomes very fluid as the temperature is increased from 245°F. to 255°F. It will neither freeze nor drool at the nozzle or secondary sprue operating at temperatures from 260°F. to 290°F.

Material B is stiff flowing and would freeze in the nozzle until the temperature is increased to above 290°F. The plastic would drool out of the nozzle if the temperature is increased to above 300°F. This is a much narrower temperature range than material A and closer nozzle temperature control would be required.

Material C would also require a narrower nozzle temperature range than material A because it is more temperature sensitive. With the nozzle varying in temperature within the indicated limits, material C could either freeze or drool. The nozzle temperature would have to be very carefully controlled to operate from 270°F. to 275°F. to successfully run material C.

Obviously, material A would be the easiest to run because it has less change in fluidity with small temperature changes.

Plastiatrics studies on this and other phases of plastics formulation, design, molding and finishing continue under the direction of Dow Plastics Technical Service Engineers. For your copy of the paper entitled "Molding Materials for Present and Future Molding Techniques", or for further information on these Plastiatrics studies, write THE DOW CHEMICAL COMPANY, Midland, Mich., Plastics Sales Dept. 1522F.

YOU CAN DEPEND ON DOW

SPE JOURNAL

VOL. 14 MAY, 1958 No. 5

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● Entered as second-class matter at the Post Office at Athens, Ohio.

● "WHAT SPE CAN DO FOR YOU" — This is the title of a new brochure just published by the Membership Committee. It tells the story of SPE — a story that will be interesting and valuable to many members as well as to those who are contemplating membership. It also contains information on how to join and a folded-in application blank. Copies are available to Section Membership Chairmen, members and prospective members by writing to Society of Plastics Engineers, 34 E. Putnam Ave., Greenwich, Connecticut.

● QUALITY CONTROL — A meeting featuring many items of interest to SPE members is the National Convention of the American Society for Quality Control, May 26, 27 and 28. Convention Headquarters are the Statler and Sheraton-Plaza Hotels, Boston, Massachusetts.

● CUMULATIVE INDEX — Now available for the first time is an index listing all Technical Papers published in the SPE Journal up to January 1, 1958. This valuable reference is available for $1.00 from Society of Plastics Engineers, 34 E. Putnam Ave., Greenwich, Connecticut.

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This Month's Cover

High-gloss integrally-colored refuse can made of Bakelite high-density polyethylene features rigidity, impact resistance and easy cleaning. According to the molder, Dapol Plastics Inc., Worcester, Mass., the plastics receptacle unit bodies are injection molded at the rate of 75 per hour, lids and foot pedals at 90 per hour. Stress-cracking was not a problem with the high density polyethylene material.

hi-fax®.. the high-density

Looking at high-density polyethylenes for improved products and lower costs?
Then be sure to check Hi-fax.

Here's why Hi-fax is different:

Hi-fax, as produced by Hercules' exclusive process is different in nature and performance from all other high-density polyethylenes. It is formulated at a density which provides optimum performance in terms of the key properties you need.

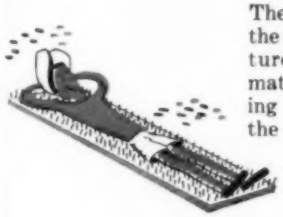
Different because: Temperature Resistance

From boiling water to sub-zero temperatures, Hi-fax retains its dimensional stability, flexibility, and impact strength. Non-toxic, too, it's the ideal plastic for housewares, containers, toys, and food packaging.

Different because: Lightweight

Providing rigid strength in thin-wall sections, Hi-fax, lightest of all high-density polyethylenes, yields extremely lightweight, highly functional structures.

Different because: Rigidity



The stiffness of Hi-fax permits the design of thinner wall structures, substantially reducing material costs without sacrificing appearance or function in the end product.

Different because: Toughness

Unbreakable and abrasion-resistant, Hi-fax provides a sturdy, low-cost plastic for heavy-duty industrial applications, mechanical uses, pipe, wire and cable, film and paper coatings.

Different because: Stress-Crack Resistance

No other high-density polyethylene can match the stress-crack resistance of Hi-fax. This key property makes Hi-fax the preferred polyolefin in detergent packaging, wire and cable coatings, and any other uses where resistance to embrittlement due to atmospheric or chemical exposures is important.

HERCULES

THREE NEW MATERIALS FOR THE PLASTICS INDUSTRY

Hi-fax High-density polyethylene • Pro-fax® Polypropylene

Penton® Chlorinated polyether

*Hercules trademark

polyethylene that's different

Need a custom-built high density polyethylene exactly tailored to your market?

Only Hi-fax gives you a choice of 7 end-use types.

1. Injection Molding

A broad selection of injection molding types offering the optimum in physical properties, moldability, color and finish in four different melt index ranges.

Royal thermos jug has base, cap and handle molded with Hi-fax by Avsco Inc., Excelsior Springs, Missouri.

2. Blown Containers

The only high-density polyethylene especially formulated for blow molding. Produces lightweight, thin-wall containers with outstanding heat, chemical, and stress-crack resistance.

Another first for Hi-fax! Thermoplastic syrup jar at left molded by Royal Manufacturing Co., Prescott, Arizona, for Maynard Manufacturing Co., Glendale, California.

3. Pipe

An exclusive Hercules formulation, based on more than three years of laboratory and field testing, designed to yield better plastic pipe at lower cost.

Hi-fax can be fabricated in conventional equipment, yields uniform wall thicknesses even in large diameter pipe.

4. Extrusion

Your choice of four extrusion grades specifically formulated to provide the combination of physical and mechanical properties required in your process and products.

By using Hi-fax tubing in its sash balance assembly, Unique Balance Company makes an already fine product an even better one.

5. Wire and Cable

Three special grades providing outstanding abrasion and stress-crack resistance, the two properties most important to the electrical industry.

Hi-fax produces low-cost plastic-coated tree wire capable of withstanding rugged, long-term exposures to abrasion and weathering.

6. Film and Paper Coating

Special grades with excellent workability, acceptable for direct contact with foods, and yielding low-cost films and paper coatings.

7. Monofilament

Resins which yield rope, cordage and fabrics with excellent "hand" and "feel", high tensile strength, abrasion resistance, flexibility and washability.

Cellulose Products Department

HERCULES POWDER COMPANY

INCORPORATED

900 Market Street, Wilmington 99, Delaware

CPSB-8

HPM PREPLASTICIZER

Extremely Fast... Exceptionally High Injection Rate... Each Shot Exact In Weight

After being rigorously tested for many months in actual plant operation, these new, fast H-P-M preplasticizing injection machines came up to our every expectation. One machine speeded up large parts production for its owner by over 100% . . . the molding superintendent says "it's the machine of the future." Absolute shot size control is accomplished by the combination operation of a rotary material control valve and an adjustable nut for accurately measuring each shot of material. Let us tell you what these new machines will do for you. Call in a near-by H-P-M engineer or write for complete information today.

A COMPLETELY NEW CONCEPT IN PREPLASTICIZING

These machines are built in three sizes—450-ton—80 oz.; 800-ton—200 oz.; 1500-ton—300 oz. The 80 oz. and 200 oz. machines are illustrated above. They are ideal for filling deep, thin-walled sections or large areas that must be filled rapidly. Parts are better in quality and uniform in size and weight.

Specifications

MACHINE MODEL	450-P-80	800-P-200 SPECIAL	1500-P-300
Material Injected Per Cycle (Oz./max.)	80	200	300
Clamp Tonnage	450	800	1500
Plasticizing Capacity (Lbs. Per Hr.)	200	300	400
Mold Space (Max.)	26½"x36"	36"x55"	48"x72"
Daylight	40"	84"	106"
Mold Thickness (Min. Without Spacer)	15"	30"	46"
Stroke	25"	54"	60"
Rate of Injection (Cu. In./Min.)	1530	5300	6640
Horsepower	75	225	275

Note: Machines can be equipped for higher speed injection if desired.

H828

THE HYDRAULIC PRESS MFG. COMPANY

A DIVISION OF KOEHRING COMPANY • MOUNT GILEAD, OHIO, U. S. A.

HPM

The Society of Plastics Engineers, Inc.

An international scientific and educational organization of more than 6500 individual members devoted to the development and dissemination of technical information in the fields of research, design, development, production and utilization of plastics materials and products. The Society is incorporated under the laws of the State of Michigan.

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●

Membership in the Society is extended to individuals who by previous training or experience or by present occupation qualify them to carry out the objectives of the Society. The privileges of membership are designed to enhance the professional standing of the individual member by encouraging participation in scientific and technical programs and professional activities; by developing close personal contacts and acquaintanceship between members; and by providing an opportunity to administer the local and national activities of the Society.

●

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CO-CHAIRMEN FOR 15th ANTEC

James T. Growley Guy A. Martinelli

Jim Growley and Guy Martinelli are the initial driving forces of what is expected to be the biggest ANTEC.

Jim has been with the Celanese Corporation since 1936. By 1949 he had risen to his present position of District Sales Manager.

The operations of ANTEC are very familiar to Jim. In 1951 he served as a General Co-Chairman of the 7th ANTEC held in New York. Jim is Golf Committee Chairman of the New York Section of SPE, and is also a member of the SPI.

Combining efforts with Jim is Guy Martinelli as General Co-Chairman. Guy joined Sylvan Plastics Inc., a subsidiary of American Viscose Corporation in April of 1956, and is now Sales Manager. At the present time Guy is President and Chairman of the Board of Directors of the New York Section of the SPE.

SPE Technical Meetings

15th Annual Technical Conference

January 27-30, 1959 The Commodore Hotel, New York

1958 RETECS

Plastics in the Automotive Industry

September 12 St. Clair Inn Detroit

Write for information to John D. Young, E. I. du Pont de Nemours & Co., Inc., 13000 W. Seven Mile Road, Detroit 35, Michigan.

Plastics in Packaging

October 1 Statler Hotel Hartford, Connecticut

Write for information to Blakely McNeill, Fuller Brush Co., 3580 Main St., Hartford 15, Connecticut.

Epoxies

October 21 Upper Midwest

Write for information to Russ Kirby, Minnesota Mining and Manufacturing Company, 900 Farquier, St. Paul, Minnesota.

Electronics

October 24 Stanford Research Institute, Menlo Park, Calif.

Write for information to Julius W. Talen, c/o Lenkurt Electric Co., Inc., San Carlos, California.

Building and Construction

November 13 Southern California

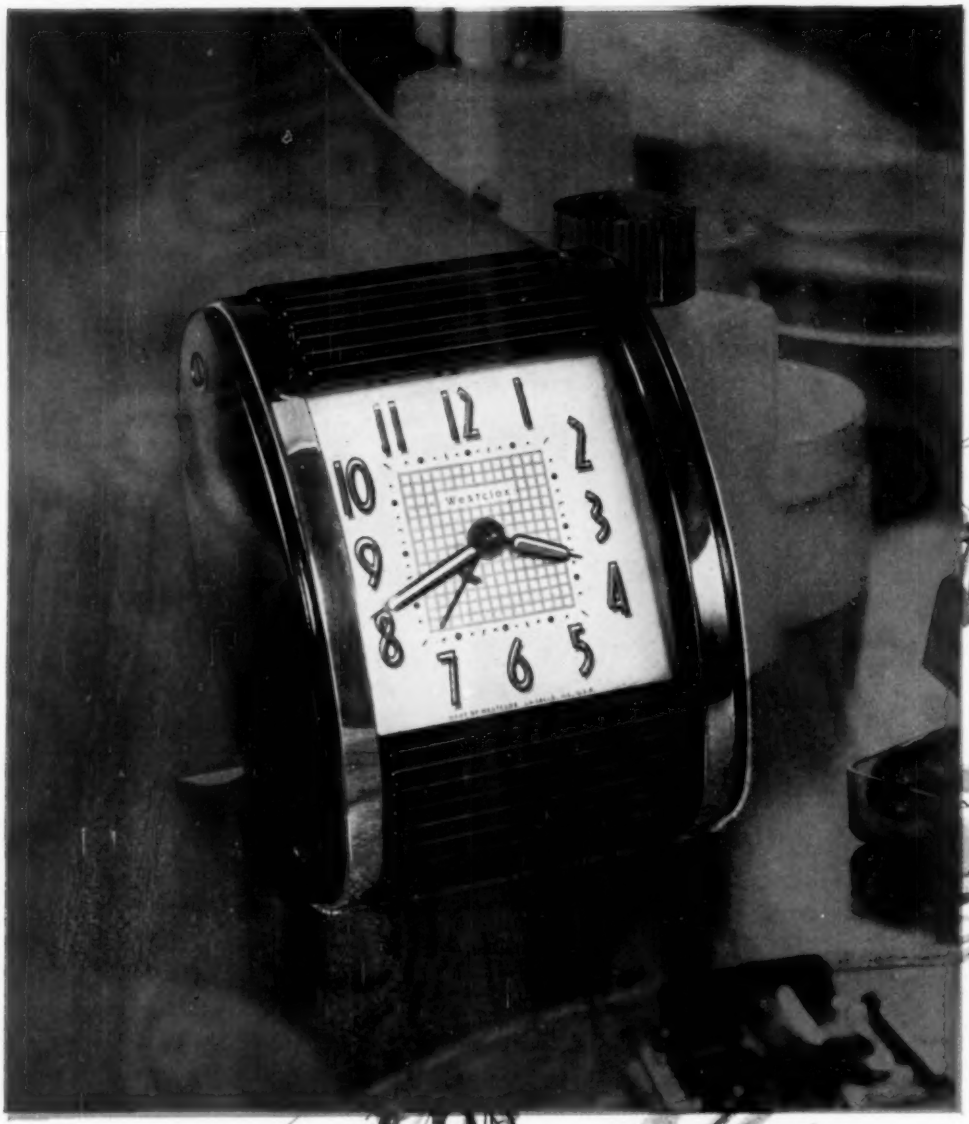
Write for information to John Delmonte, General Chairman, Furane Plastics, Inc., 4516 Brazil Street, Los Angeles, California.

1959 RETECS

Plastics in the Metal Industry

May 7, 1959 Pittsburgh

Write for information to John Parks, Hydraulic Press Manufacturing Company, 512 Empire Building, Pittsburgh 22, Pennsylvania.



TYPICAL PHYSICAL PROPERTIES OF FORTICEL

Flow temperature: (°C.) (A.S.T.M.)	D569-48	167–178
Specific gravity	D176-42T	1.18–1.21
Tensile properties:		
Yield (p.s.i.)	D638-52T	3380–5020
Break (p.s.i.)	D638-52T	3470–5240
Elongation (%)	D638-52T	56–66
Flexural properties:		
Flexural strength (p.s.i. at break)	D790-49T	6400–8500
Flexural modulus (10^6 p.s.i.)	D790-49T	0.23–0.30
Rockwell hardness: (R scale)	D785-51	62–94
Izod impact: (ft. lb./in. notch)	D256-43T	2.7–11.0
Heat distortion: (°C.)	D648-45T	59–70
Water absorption:		
% sol. lost	D570-42	0.00–0.08
% moisture gain	D570-42	1.5–1.8
% water absorption	D570-42	1.6–1.8

WESTCLOX SELECTS FORTICEL

Celanese propionate thermoplastic for its popular "Travalarm"

Trim cargo for the traveler, the Travalarm is a fashion-wise member of the Westclox family of precision-made electric and spring-wound clocks, pocket and popularly priced wrist watches. A handsome traveling companion, the Travalarm comes in either an ivory or black case of lustrous Forticel.

Westclox joins other famous name manufacturers like Zenith, Bissel, American Optical, Ansco, in selecting Forticel because this thermoplastic offers something more in a production material—the toughness and high speed moldability of the cellulosics, and the big plus combination of better dimensional stability, excellent form retention, freedom from unpleasant odor.

Properties like these can give your products an important competitive advantage, too. Write Celanese for complete data. Or, use coupon below.
Celanese Corporation of America, Plastics Division, Newark, N. J.
Canadian Affiliate: Canadian Chemical Co., Limited, Montreal, Toronto, Vancouver.

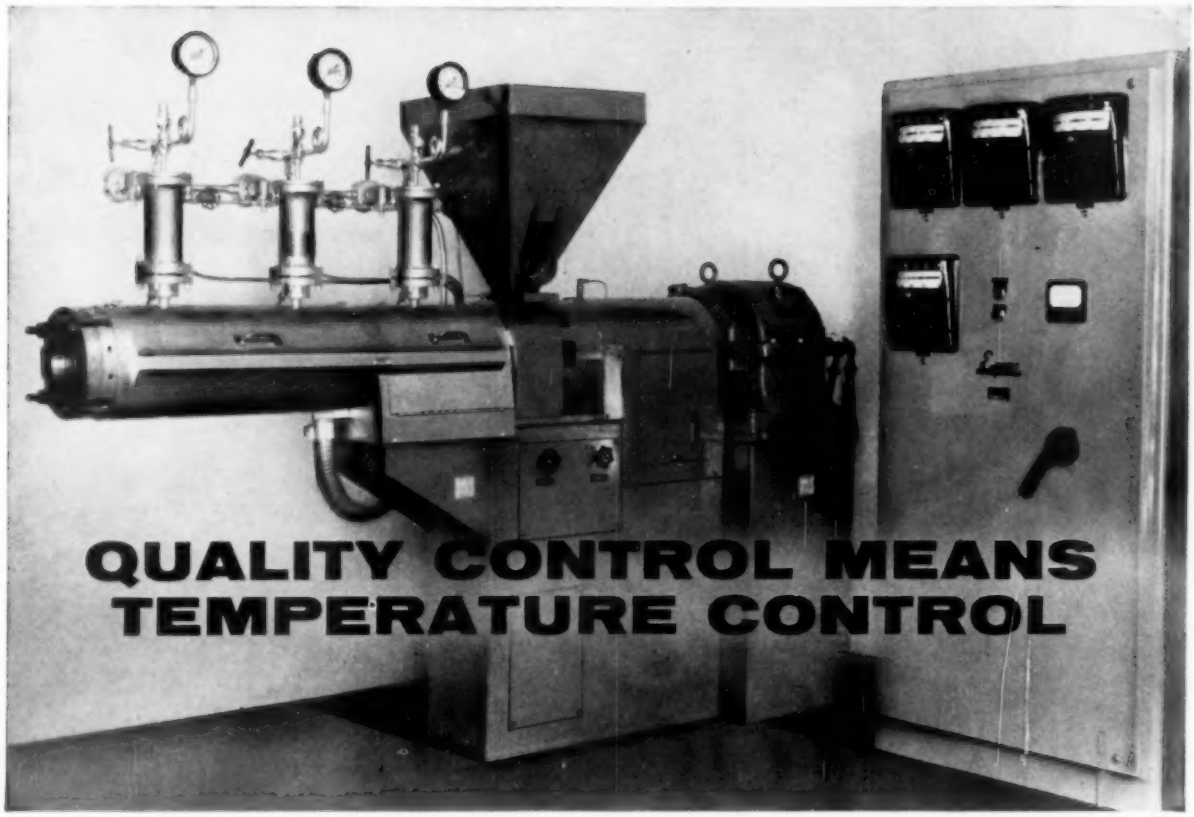
Export Sales: Amcel Co., Inc., and Pan Amcel Co., Inc., 180 Madison Avenue, New York 16. Celanese ® Forticel ®

Celanese
PLASTICS

Molded by
American Plasticraft, Chicago, Ill.

Celanese Corporation of America, Plastics Division
Dept 170–E, 744 Broad Street, Newark 2, N. J.
Please send me New Product Bulletin NP-16 on Forticel Plastic.

NAME_____
TITLE_____
COMPANY_____
ADDRESS_____
CITY_____ ZONE_____ STATE_____



QUALITY CONTROL MEANS TEMPERATURE CONTROL

Egan Extruder With "Willert Temperature Control System" Automatically Eliminates Temperature Variations

Heating the plastic material in the extruder cylinder, whether by conduction, induction, or friction, is no problem — assuming the designer has provided sufficient heating capacity and a properly designed screw.

However, provision for efficient dissipation of excessive heat is essential to make any temperature control system complete.

The Willert System is the ultimate in complete control! Excessive heat is removed automatically without moving parts, and without any manual operation of valves or switches by the operator. As a result, closer tolerance extrusions are produced easier and faster.

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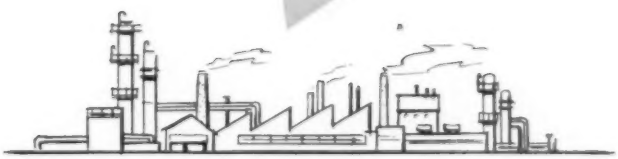

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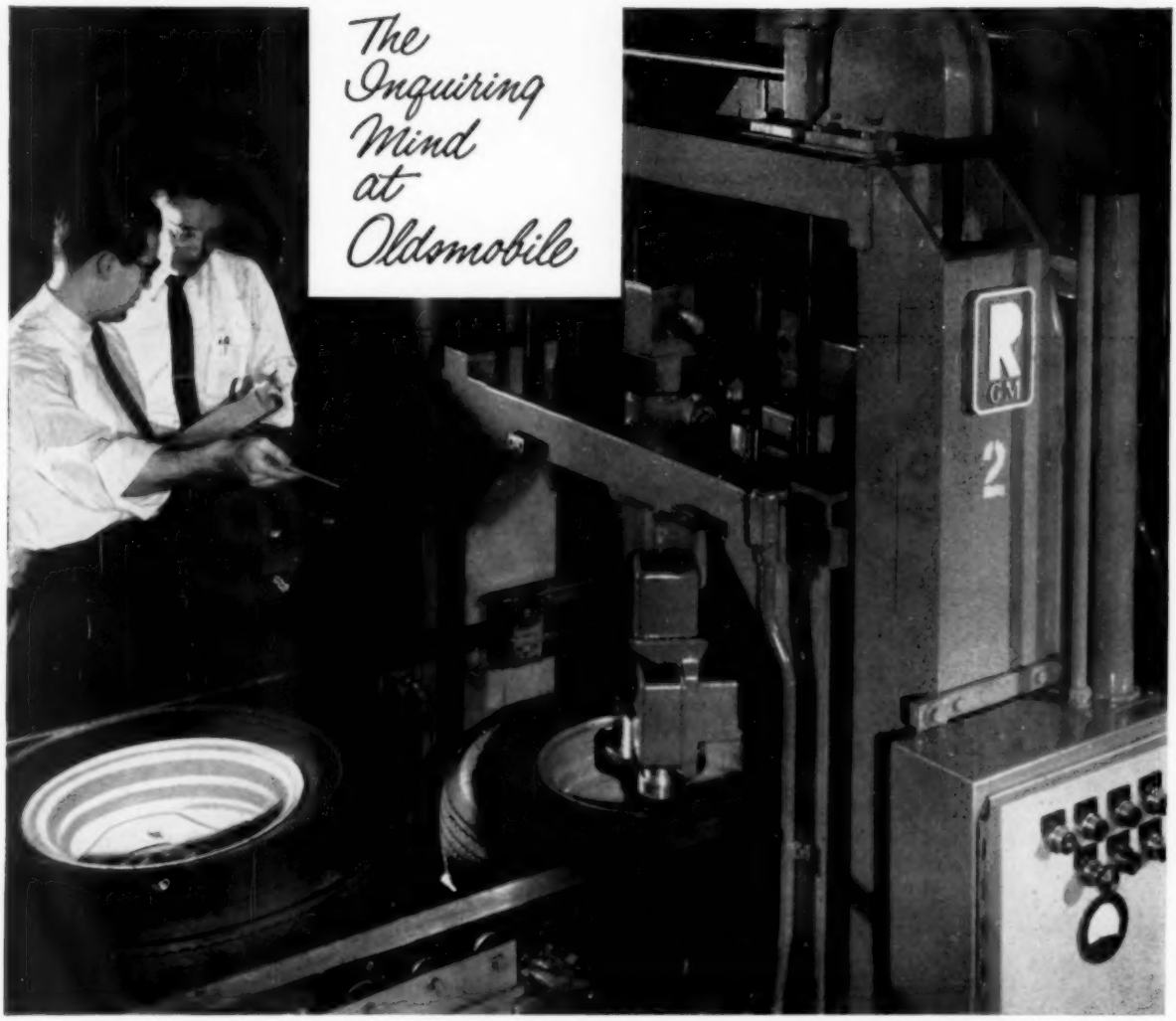

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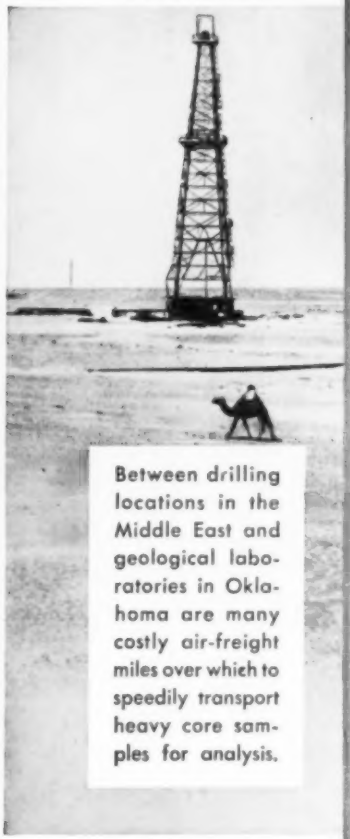
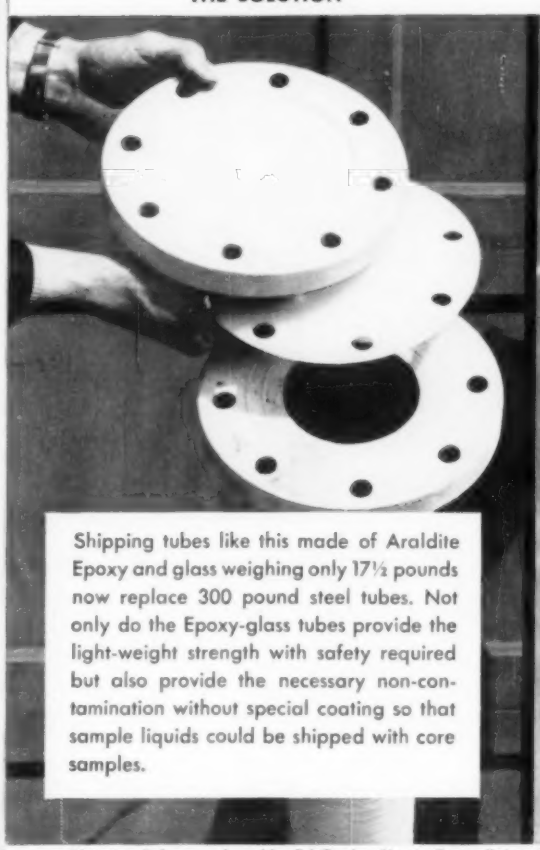


Between drilling locations in the Middle East and geological laboratories in Oklahoma are many costly air-freight miles over which to speedily transport heavy core samples for analysis.

THE SOLUTION



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PLASTICS ENGINEERS JOURNAL

Volume 14, Number 5 • May, 1958

INSULATIVE AND CONDUCTIVE COATINGS

To meet the demand for better electrical coatings in today's aircraft, constant development of resins is essential. This survey shows typical properties of resins currently being used for these coatings.

Elbert Davis
Plas-Kem Corporation
Burbank, California

RESINOUS MATERIALS currently available for use in insulative and conductive coatings are discussed briefly in this survey to allow comparison of electrical properties. Applications are cited to indicate possible end uses.

INSULATIVE COATINGS

Epoxy

Straight amine catalyzed epoxy coatings find their main use in the electronics field in applications where their excellent adhesive properties, low shrinkage, superior penetration, and rapid cure, even in thick sections, can be used to advantage. However, the high polarity of the resins and their inherent permeability to moisture cause the electrical properties to degrade rather severely at elevated temperature and high humidities. This change in dielectric properties of the standard epoxies, with temperature, limits their use to low frequency applications.

This paper was presented at the Southern California Second Regional Technical Conference of SPE.

However, the epoxy resins may be co-reacted with a wide variety of "hardeners" such as acid anhydrides, polyfunctional aromatic amines, polyamides, urea and melamine resins, phenolic resins, polyvinyl formal, isocyanates, and polysulfides. These "modified" epoxy systems in many cases have greatly improved electrical properties and better retention of properties at elevated temperatures.

Modified Epoxy

Modified epoxy coatings with exceptional electrical properties are available for spray, brush, or dip application (1). These coatings pass the difficult requirements of specification MIL-STD 202 method 106 which measures surface resistance during a 10-day humidity cycling from room temperature to 160°F at 95 to 100% relative humidity.

The coatings can meet the specification on both phenolic and epoxy boards. But in either case a minimum thickness of 8 mils must be applied. Three coats of the spray type material or one coat of the dipping material will apply approximately 8 mils. The spray type material

can be catalyzed and used within its 45 minute pot life or the liquid components can be blended externally by use of a two component spray gun (2). The catalyzed dipping mixture has a pot life of about 3 hours and this life may be extended indefinitely by a 50% replenishment with fresh material every hour. The coating is applied at room temperature by immersing the printed circuit board and withdrawing at a rate of about 4" per minute.

These coatings, when cured 2 hours at 75°C exhibit the following electrical properties:

	Spray type	Dip type
Surface Resistance in megohms (after 10 day humidity cycling)	3.4×10^5	125×10^5
Dielectric Strength—volts per mil (10 mil film)	1350	2000
Dielectric Constant at 1 mc	3.48	3.01
Power Factor at 1 mc	.0285	.0279

Odorless Liquid Polymer Extender

Odor free liquid polymer extenders (hydroxy terminated polyethers) are available, (3) for modifying the working properties and the physical properties of epoxy resins.

The modifiers with viscosities as low as 50 poises may be used to advantage in compounding low viscosity 100% solids liquid epoxy coating systems having improved flow and sealing properties.

Lower exotherms give increased pot life and extended working time, but full cures can still be obtained at room temperatures.

The liquid polymer extenders can be used to improve the flexibility and resilience of the epoxies with fair retention of electrical properties. For example, equal portions of low viscosity extender and liquid epoxy resin cured at room temperature with 12% diethylene triamine in the resin produced a coating with approximately 50% elongation and the following electrical properties:

Surface Restivity	1×10^{12} ohm-cm
Dielectric Constant at 1 kc	6.0
Dissipation Factor at 1 kc	0.003

Polyvinyl Acetals

Polyvinyl formal (4) is an extremely tough thermoplastic resin which has found its main electrical insulative use in the manufacture of tough heat resistant wire enamel. In this use the Formvar resin is combined with alkyl phenolic resins and the coatings are heat cured to a cross-linked material with good physical and electrical properties.

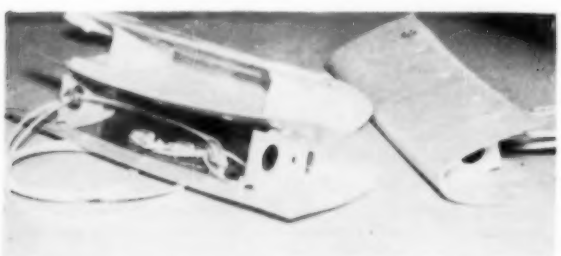

Figure 1. A 350-Watt, 28-Volt Organic Electrofiim Heater Incorporated on a Canadair Air Intake Scoop.

Similar solution coatings based upon both polyvinyl formal and polyvinyl butyral are being used by fabricators of electronics components whenever a thin heat resistant and shock resistant insulative base coat is required. These coatings have excellent adhesion and provide an excellent base for heavier top coatings of alkyd, epoxy, or isocyanate resins.

Polyurethane Wire Enamels

Polyurethane coatings are being used to advantage as insulative coatings on wire and in some cases are outperforming polyvinyl formal. The polyurethanes have the unique quality of easy removal at soldering temperatures without leaving carbonized residues. They do not require the use of mechanical or chemical strippers and in many cases no flux is needed to get clean corrosion-free solder joints.

Polyurethane Coatings

Liquid isocyanate polymers are now available (5) and techniques have been developed for satisfactory spray, dip, or brush coating of these materials in electrical applications.

Compositions may be formulated at 100% solids so that deep voids may be filled and sealed at the same time a thin coating is being applied to other parts of a component. Or solvent diluted formulations may be prepared where faster spray application of the coating is desired or where close tolerance on coating thickness is required.

The use of partially polymerized isocyanates instead of the monomeric diisocyanates not only reduces the toxicity hazard of handling these materials but decreases the chemical reactivity to a point where practical pot life and handling times up to one hour can be obtained. However, because some free diisocyanates are present in the liquid polymers and because free amines may be present in the curing systems, normal precautions for handling these materials should be observed.

In order to produce bubble-free coatings using the 100% solids formulations, extreme care must be taken to eliminate all gases during mixing and application of the materials. First, the liquid polymer should be heated and placed under vacuum to remove air and moisture. Then the preheated curing agent should be added and the mixture exposed to vacuum again to remove gases formed by the reaction of the diisocyanate with moisture and with organic acids present in the system. Finally, best results are obtained if the surface to be coated is prewarmed to eliminate any trace of moisture.

Solvent diluted systems are simpler to use. The lower viscosity of these solutions facilitates removal of air and gaseous by-products and they do not require heating or vacuum treatment before application.

Curing systems can be selected for either room temperature or elevated temperature cure.

Typical electrical properties of a room temperature cured polyurethane coating at 50% relative humidity are as follows:

	At 80°F
Surface Resistivity in ohm-cm	1.5×10^{13}
Dielectric Constant at 1 kc	4.7
Dissipation Factor at 1 kc	0.1400

No change in electrical properties was evident after 7 days aging at 250°F. Elevated temperature cure generally results in improved electrical and physical properties.

Polysulfide

Liquid polysulfide polymers find use as insulative coatings not only because of their moderately good electrical properties but because of other unique physical and chemical properties.

The polysulfides are generally considered for use when a very soft resilient coating is required. Although the polysulfides can not compete with the soft silicone rubber coatings in electrical properties, particularly at elevated temperatures, the polysulfides do have superior toughness and adhesion (without primers) and superior resistance to oils, fuels and solvents. These latter properties make them ideally suited for airborne applications where extreme vibration and exposure to aircraft fuels might be involved. Deficiencies of polysulfide coatings which should be kept in mind are poor high temperature aging properties, poor resistance to cold flow and high dielectric constant.

Typical electrical properties for a filled polysulfide coating (compared with silicone rubber) are as follows:

	Polysulfide	Silicone Rubber
Dielectric Strength (volts/mil)	251	340
Dielectric Constant 1 kc at 25°C	10.3	3.9
Power Factor, 1 kc at 25°C	.004	.005
Volume Resistivity 25°C (ohm-cm)	6.1×10^{11}	6.8×10^{15}

Vinyl

It can be shown that the electrical properties of vinyl resins improve with decreasing plasticizer content. In the preparation of vinyl solution coatings and organosol dispersions the formulator is not limited as is the case with molding or extrusion compounds. Because of the fluidity of the solvent systems very low plasticizer-to-resin ratios can be used and the optimum physical and electrical properties of the resins realized.

A typical vinyl organosol compounded with 15% plasticizer at 75% solids and fused at 350°F produces a hard, tough and flexible coating with 140% elongation and a DC resistance of 3×10^{14} ohm-cm at 50°C.

Vinyl solution coatings which offer the convenient advantages of spray application and fast air drying are being used as insulative top coatings where rough handling, strong vibration, high humidity, salt spray, and oils or chemicals are likely to be encountered.

In a typical example, (6) a complete actuator assembly was sealed with epoxy resin and completely coated with a vinyl solution coating. The actuator was (a) subjected to water spray, (b) subjected to a 72 hour soak at 250°F, (c) subjected to vibration in three planes from 17cps to 254cps, (d) subjected to an oil and fuel drip test of ½ pint of fluid per hour for 48 hours at 140°F. After all of these tests there was no evidence of breakdown of the coating and no fluids had leaked into the actuator during the tests.

Fluorinated Resins

Although completely fluorinated resins (7) can be deposited in the form of insulative coatings from water dispersions of the resin, high temperatures are required to fuse the dispersed particles into a continuous film.

Partially fluorinated resin (8) exhibits many of the properties of completely fluorinated materials: e.g. excellent water and water vapor resistance, resistance to strong chemicals, good fungus resistance, and good high-temperature resistance and it has the advantage of good solubility in lacquer solvents, allowing simple brush, dip, or spray application.

The very low moisture-vapor transmission suggests the use of this type of coating as a top coat to improve other insulation materials. An example of its commercial use as an insulation coating is in the manufacture of silicone rubber insulated copper wire with a glass braid cover. The fluorinated resin is the only coating material available today which can be used as a top insulative coating to meet the difficult performance requirements of Specification MIL-W-8777 (USAF) for aircraft electrical wire.

The electrical properties of the resin are:

		1000 cycles
Dielectric Constant	24°C	2.82
Power Factor	24°C	0.01
D.C. Resistivity	70°C	5×10^{14} ohm-cm
Dielectric Strength	24°C	860 volts per mil

Silicone Rubber

Several grades of silicone gums are available (9) which can be dissolved in toluene and catalyzed with benzoyl peroxide to make unique spray, dip, or spread-coating materials. These compounds are widely used for spread coating glass fabric and tapes, glass sleeving, and glass served or braided wire. They may also be used on electrical components wherever a spray or dip coating is required to provide a thin, resilient insulative coat of silicone rubber with its excellent electrical properties. These coatings must be dried at low temperature to remove solvent without blistering and to prevent premature decomposition of peroxide catalyst. The gum thus deposited may be cured in a few minutes at elevated temperature. The exceptional electrical properties are retained unchanged even after hundreds of hours of aging at 500°F.

Typical electrical properties for a soft 40 shore silicone rubber are as follows:

Dielectric Constant (100 cps)	3.13
Dielectric Strength (volts/mil)	900
Power Factor (100 cps)	.0030
Resistivity (ohm-cm 75°F)	1.18×10^{16}

Vulcanizable Liquid Silicone Rubbers

Liquid silicone two-component systems are available both as heat curing coatings (10) and as room temperature vulcanizing coatings (11). In each case the materials are 100% solids and are sufficiently fluid for dip or spread coating or vacuum dipping. The materials may be extended with aromatic hydrocarbon solvents when lower viscosity solutions are desired for thin dip coatings or for spray application or when extended handling time is desired. The resulting coatings are resilient, serviceable from -70° to 500°F, and have good electrical properties:

Dielectric Strength (volts per mil)	460
Dielectric Constant (10^5 cycles/sec)	2.5
Dissipation Factor (10^5 cycles/sec)	.003

One important coating application which takes advantage of the unique combination of properties is the precoating of delicate vacuum tubes, precision resistors, coils, and capacitors prior to potting in epoxy resin to prevent the damage which normally would occur from the shrinkage of the potting resin.

Silicone Solution

Air dry silicone varnish (12) is being used for over coating printed circuitry to prevent moisture shorts. After air drying for 12 hours the electrical properties are:

Dielectric Strength (volts per mil)	2300
Dielectric Constant (10^6 cycles)	2.7
Dissipation Factor (10^6 cycles)	.0009
Surface Resistivity (ohm-cm 23°C)	1×10^{13}

The surface resistivity is unchanged after conditioning for 96 hours at 96% relative humidity.

Heat curing silicone varnishes (13) are used where extremely high temperature insulative coatings are required and where electrical properties must remain essentially constant at high humidities. Typical electrical properties:

Dielectric Strength (volts per mil)	1500
Power Factor (10^6 cycles)	.0043
Dielectric Constant (10^6 cycles)	2.9

CONDUCTIVE COATINGS

Conductive Silicone Rubber

Silicone rubber filled with conductive acetylene carbon black (14) has been recently announced which makes it practical to produce electrically conductive surfaces which can withstand high and low temperature cycling as well as mechanical shock and flexing and still retain their stable electrical properties. The new silicone gum has highly reactive vinyl groups capable of cross-linking and effecting a cure with low reactivity peroxides even in the presence of carbon blacks.

Since the conductive silicone has a resistivity of about 20 ohm-cm, it is possible, by blending with non-conductive Silicone Rubber, to compound a stock to meet any desired electrical resistivity between 20 ohm-cm and 1×10^{16} ohm-cm.

Applications which suggest themselves are flexible conductive coatings applied as an electrical shield over silicone insulated wire, flexible metal braid shielding, and the like. A further suggested use is for anti-static coatings which must withstand high and low temperatures as well as flexing or elongation with retention of conductivity. Tests have shown that the conductive silicone is capable of bleeding off radio frequency radiation effectively.

Organic Conductive Film Heating Elements

Conductive organic thermosetting coatings have been formulated using modified alkyd, epoxy, or silicone resins together with silver, graphite and other conductive powders (15). Sufficient chemical and physical stability have been achieved to make these coatings practical for generating heat continuously on any surface to which they are applied.

The heating elements are prepared by first spraying and baking a base insulation coat of approximately 5 mils. Then the conductive coating of a specific unit resistance required is applied also at 5 mils and cured. After attaching terminals, the entire unit is given a protective and insulative coating of 1 to 5 mils.

Unit Resistance

A convenient term which describes the resistance value of any particular conductive coating is Unit Resistance. When the thickness of the applied film is always kept constant it can be shown that the Unit Resistance is a constant for each conductive coating material and is expressed as "ohms per square." i.e.

The resistance (R) of a conductor is directly proportional to the length (L) and inversly proportional to its area (A).

$$R \propto L/A$$

The area of a film conductor is equal to the width (W) times the thickness (t)

$$A = Wt$$

But if the thickness is constant at 5 mils, the length and the width determine the resistance.

$$R \propto L/W$$

or

$$R = \Phi\, L/W \text{ where } \Phi \text{ is a constant.}$$

Since L/W equals the number of geometric squares, Unit Resistance $\Phi = \dfrac{R}{L/W}$ = ohms/squares = ohms per square. The unit resistance of the most common organic conductive coatings mixtures ranges from about 0.1 to 50 ohms per square.

The resistance of a conductive coating may be varied by changing the following variables:

1. The geometry of the coating
2. The thickness of the coating
3. The ratio of more conductive to less conductive pigments and the ratio of total pigment to the resin binder.

In general, the shape of the part determines the shape of the conductive element and the thickness is usually held constant. The proper selection of pigments and the proper adjustment of the ratio of the more conductive to the less conductive pigment, then, is the most practical manner of controlling the unit resistance of the coating.

For any heating element application, the power requirement (W) and the voltage (E) are generally known and fixed. In the simple case, these fixed values determine the resistance of the element.

$$R = E^2/W$$

From the dimensions of the element, the number of squares L/W can be calculated, and the ohms per square R/Squares determined. The fabricator then simply selects the conductive mixture which has the correct ohms per square unit resistance Φ, and sprays on the predetermined film thickness. Measured resistance values can be held within a few per cent of theory.

Organic conductive coatings can be prepared which will operate safely at temperatures up to 350°F and at 28, 110, and 220 volts. Watt densities are in the order of 0 to 30 watts per square inch. The films can withstand as much as 2000 volts Hipot in an insulation breakdown test. Other requirements which can be met are the fungus resistance, salt spray, and humidity cycling tests of specification MIL-E-5272A and the vibration tests called out in MIL-E-5257A.

Figure 2. Rocketdyne Liquid Oxygen Valve Heaters made of Electrofilm Maintains a Temperature of 0°F.

The thermal characteristics of film heating elements are ideal because of the low mass of the coating (less than 0.1 lb. per square foot), the large area for heat distribution, and the extremely close contact with the surface to be heated making heat flow almost instantaneous.

Organic conductive film heaters have been applied to: air scoops, rocket tubes, telemetering cases, black box tube sets, crystal ovens, and gyro cases.

Inorganic Conductive Coatings

Conductive coatings composed of a blend of ceramic nonconductors fused together with powdered metallic conductors (16) are finding increasing use in aircraft and missile applications as operating temperatures continue to rise.

The main use of the coatings to date has been in the production of heating elements on curved or irregular metal surfaces when fast heat transfer, thermal stability, and light weight are required.

The elements are made by first spraying and fusing an insulative vitreous enamel base insulation approximately 4 mils thick and having 1000 to 2000 volts dielectric strength. Then the heating element composition is sprayed on. This latter consists of a mixture of fusible frits, glasses, metallic salts and clays together with metallic particles, the composition being adjusted so that it will fuse into a sintered structure of the desired conductivity. Sufficient control of the variables has been achieved to allow production of conductive films with predictable resistance values from .01 ohm per square to 1000 ohms per square. The heating element then is usually insulated with an organic top coat to meet the environmental requirements of the intended application.

The elements generally meet the requirements of specification MIL-E-5272A and are capable of operating at temperatures from —250°F to 500°F. Intermittent operation at 700°F has been successful. Resistance to alkali, acid, chemicals and oxidation is good and exposure to salt spray for 500 hours has no effect. Watt densities up to 40 watts per square inch are common and the upper limit (up to 100 watts per square inch) is generally determined by the ability to remove heat from the surface and avoid developing destructive temperatures of 900° to 1000°F.

The inorganic conductive heating elements have found use on air scoops, aircraft cabin air heaters, gear housing heaters, temperature controllers for transducers, accelerometers, gyros and batteries.

Conductive Silver (17)

Air drying conductive silver coatings are essentially lacquer-type coatings with powdered silver added. Their use is somewhat limited by their poor adhesion and abrasion resistance and poor solderability. Their main application is in the field of static shielding and as a conductive base coat on plastics or other nonconductors which must be electroplated.

Heat curing thermosetting silver coatings make use of epoxy binders and show improved adhesion and abrasion resistance over the air drying lacquer type. The unit resistance of these coatings is in the order of 2 ohms per square or less.

The most important conductive silver coatings for electronics applications are the type which requires firing up to 1500°F on ceramic glass and mica insulators. The coatings contain 50 to 80% of silver powder (smaller than one micron in particle size) and low melting finely powdered glasses dispersed in a liquid plastics binder solution. The conductive coatings, after firing, have a unit resistance less than 0.01 ohm per square. The high conductivity combined with the excellent adhesion, abrasion resistance and solderability make the fired coatings very useful for disc, plate, and tubular capacitors, mica capacitors, and ceramic base printed circuit units such as vertical integrators and audio coupling circuits.

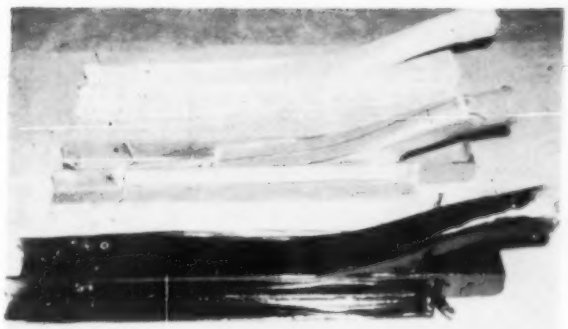

Figure 3. Organic Conductive Film Heating Element on a McDonell Aircraft Air Intake.

A specialized application which makes use of both fired and air dried silver coatings (applied by silk screen techniques) is the manufacture of delay lines.

Electronics design engineers are confronted with the problem of storing or delaying information for short intervals of time in radar, computer, and telemetering applications.

Delay times in the order of microseconds may be attained by the use of electrical networks composed of high inductance coils wound on a small diameter grounded tubular core. A silver conductive coating is applied to the ceramic core and scribed with longitudinal stripes to reduce eddy current loss. The conductive coating is then fused at about 1500°F. The cores are insulated by wrapping with polyester or fluorocarbon film or by coating with a high dielectric thermosetting resin and the tube is then wrapped with its required coil windings.

To minimize distortion of signals, small bridging capacitors of a physical size in the same order of magnitude as the resonant wave length are added across the line. In the interest of compactness for missile use these capacitors are made in the form of tiny patches of silver powder bonded with flexible alkyd or epoxy resins and applied by silk screen techniques to strips of polyester tape. The tape is then wrapped around the line after the coils are wound. The entire unit is usually encapsulated in epoxy resin.

Notes

(1) Houghton Hysol 6131 and 6132
(2) DeVilbiss #JGC-501 with #78 Air Cap and FF Tip
(3) Thiokol EM 206 and 207
(4) Shawinigan Formvar
(5) Thiokol Solithane 113
(6) Cico Corporation
(7) DuPont Teflon
(8) Firestone Exon 461
(9) Dow Corning, General Electric, Union Carbide
(10) Dow Corning Silastic S-2007
(11) Dow Corning RTV-501
(12) Dow Corning DC-991
(13) Dow Corning DC-996
(14) Union Carbide X-1516
(15) Electrofilm Corporation
(16) Thermolab Corporation
(17) DuPont

SCREW–EXTRUDER PUMPING EFFICIENCY

As Influenced by Relative Channel Depth and Curvature

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The basic theory of isothermal screw extrusion has in the past been presented in two forms:

1. The two-dimensional or so-called "exact" theory in which the edge effects of the flight faces are taken into account (4), and

2. The one-dimensional or so-called "simplified" theory in which these edge effects are neglected and which is therefore limited in application to screws of relatively shallow depth (3).

There has existed a tendency for the latter one-dimensional theory to become the working tool, while the two-dimensional theory for the most part has been used only by those persons intimately interested in screw extrusion theory, *per se*. Several reasons for this situation exist. In the first place, the relationships derived on the basis of the two-dimensional theory have been put into forms which are sufficiently different from those based on the one-dimensional theory that direct comparison and transposition of calculations between the two are inconvenient. Secondly, the factors used in the past to describe the influence of flight edge effects in the two-dimensional theory, the "shape factors" for drag and pressure flow, have had no simple or immediately obvious meaning in terms of actual screw performance.

Finally, and probably in part as a result of the above, the one-dimensional theory has enjoyed considerably wider publication (1,3,5,6,7,8) than has the two-dimensional theory (4).

Although the one-dimensional theory is accurate to within about 6% for relatively shallow screws, *i.e.*, screws having channel depth-to-width ratios of 0.1 or less, it is reasonable to conclude for one or more of the above reasons that this simplified theory is frequently applied to deeper-flighted screws where its limitations are severe and, unfortunately, usually unappreciated.

In addition to the deeper-flighted screws which fall into the category of more conventional design, considerable recent interest has been shown in extractor screws (2). The extraction section in such a screw is made relatively deep so as to expose to vacuum the largest possible fluid surface. In this case the problem of estimating the pumping capacity or, the equivalent, estimating the degree full to which such a screw section will operate, is complicated by the very fact that the screw channels are not completely filled with fluid.

Along with flight edge effects, one other factor assumes importance when estimating the performance of deep-flighted screws—that being the fact that the screw channel itself is curved rather than being flat as it is pictured in the flat-plate model which is customarily used as a basis for analyzing extruder-screw performance.

Convenient, easy-to-use methods have been developed whereby both of these factors, *i.e.*, flight edge effects and screw channel curvature, can be taken into consideration when calculating screw melt-pumping rates in either full or partially empty screw sections.

One-Dimensional Extrusion Theory

The one-dimensional extrusion theory has been thoroughly discussed in the literature (*loc. cit.*) and will therefore be only briefly summarized here. The basic fluid flow-components which are considered are shown in Figure 1. Here, Q_d represents the so-called drag flow, *i.e.*, the flow down the channel caused by the shear on the fluid induced by the relative motion between the screw and barrel. This same relative motion between the screw and barrel also causes a closed-circuit rotational or transverse flow, Q_t, within the channel. Since this flow does not directly contribute to the net discharge rate, it will be ignored in the present discussion. If the extruder discharge is restricted, a pressure is built up at the die which induces an opposed pressure flow, Q_p, in the channel.

Because of the rather complex geometry of the system shown in Figure 1, it is found convenient to picture an extruder screw as illustrated in Figure 2. Here the screw channel has figuratively been unwrapped and laid out flat. The barrel now becomes a flat plate which moves over the screw channel in the direction noted.

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If the edge effects of the screw flights are ignored, *i.e.*, if the flow is considered to be one-dimensional, the differential equation which describes the flow is particularly simple,

$$\frac{d^2v_z}{dy^2} = \frac{1}{\mu}\left(\frac{dp}{dz}\right) \tag{1}$$

Appropriate integrations of Equation 1 yield the familiar expressions for the velocity distribution,

$$v_z = \frac{Vy}{h} + \frac{(y^2 - hy)}{2\mu}\left(\frac{dp}{dz}\right) \tag{2}$$

and the volumetric flow rate in a single channel,

$$Q = \frac{Vwh}{2} - \frac{wh^3}{12\mu}\left(\frac{dp}{dz}\right) \tag{3}$$

The first term on the right side of Equations 1 and 2 represents drag flow; the second term, the pressure flow. The diagrams in Figure 3 show the velocity profiles of these flows as given by Equation 2.

The expression for the volumetric discharge rate can be written more conveniently in terms of the actual screw dimensions. Thus,

$$Q = \alpha N - \frac{\beta}{\mu}\left(\frac{dp}{d\lambda}\right) \tag{4}$$

where

$$\alpha = \frac{\pi^2 D^2 h\left(1 - \frac{ne}{t}\right)\sin\Phi\cos\Phi}{2}$$

$$\beta = \frac{\pi D h^3\left(1 - \frac{ne}{t}\right)\sin^2\Phi}{12}$$

N = screw rotation speed (revs./unit time)

μ = fluid viscosity

$\left(\frac{dp}{d\lambda}\right)$ = axial pressure gradient

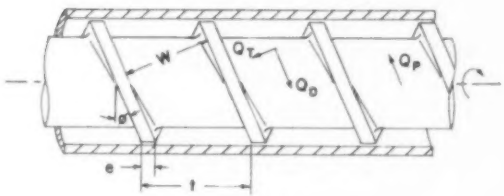
Note in particular that α and β are functions only of the screw dimensions.

The validity of Equation 4 for predicting and evaluating the performance of relatively shallow-flighted screws has been verified by several workers (6,7,8,9).

Two-Dimensional Extrusion Theory

Implicit in Equation 4 is the assumption that the screw flights do not influence the flow in the screw other than, of course, to direct the flow along the direction of the channel. The implications of this assumption can be seen by referring to Figure 4 where the actual channel velocity profile and that assumed by the one-dimensional theory are compared for the case of unrestricted discharge extrusion. It can be seen that the screw flights retard the motion of the fluid near the flight faces so that the actual flow is less than that which would exist if these edge effects were absent.

DIAGRAM OF A
SINGLE-FLIGHTED EXTRUDER



Q_D = DRAG FLOW
Q_P = PRESSURE FLOW
Q_T = TRANSVERSE FLOW

FIGURE 1

EXTRUDER WITH SCREW CHANNEL "UNWRAPPED"

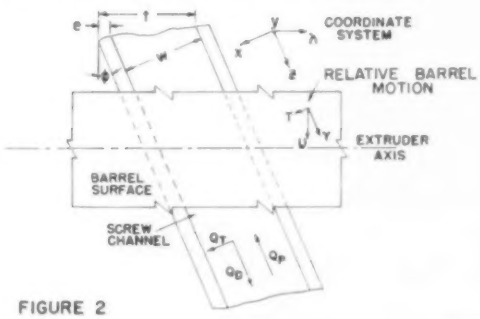


FIGURE 2

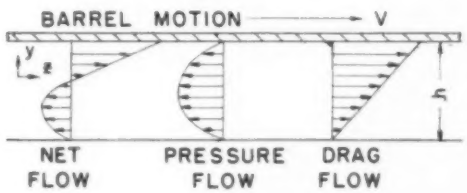


FIGURE 3

COMPARISON BETWEEN ACTUAL
TWO-DIMENSIONAL VELOCITY PROFILES
AND
PROFILES ASSUMED BY
ONE-DIMENSIONAL THEORY

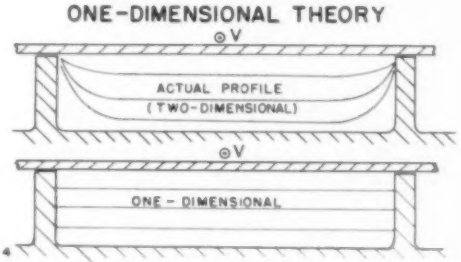


FIGURE 4

The differential equation which describes the two-dimensional drag-flow in which edge effects are considered is

$$\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} = 0 \qquad (5)$$

and that for pressure flow is given by equation 6.

$$\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} = \frac{1}{\mu}\left(\frac{dp}{dz}\right) \qquad (6)$$

Solutions to these equations have been given by Carley and Strub (4). It is not difficult to show that their solution for the volumetric flow rate can be written in the more meaningful and convenient-to-use form,

(7)

$$Q = \frac{Vhw}{2}\left[\frac{16}{\pi^3(h/w)} \sum_{g=1,3,5,\ldots}^{\infty} \frac{1}{g^3} \tanh\left[\frac{g\,\pi(h/w)}{2}\right]\right]$$

$$- \frac{wh^3}{12\mu}\left(\frac{dp}{dz}\right)\left[1 - \frac{192(h/w)}{\pi^5} \sum_{g=1,3,5,\ldots}^{\infty} \frac{1}{g^5} \tanh\left[\frac{g\,\pi}{2(h/w)}\right]\right]$$

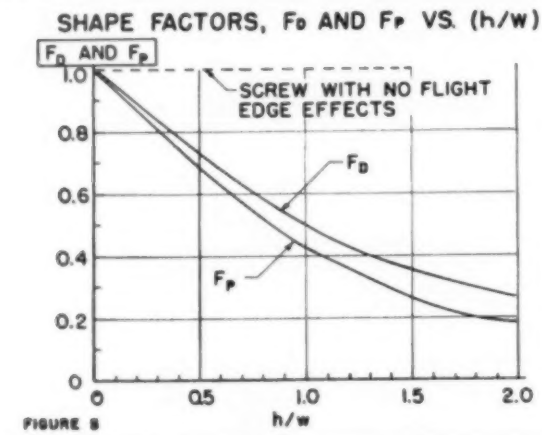


FIGURE 5

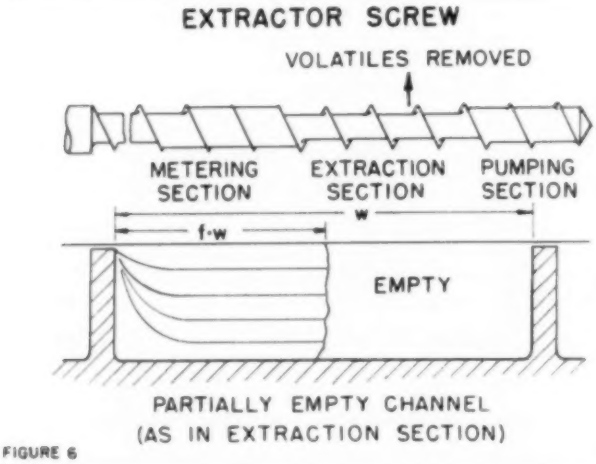


FIGURE 6

It should be noted in Equation 7 that the bracketed terms are functions only of the channel depth-to-width ratio, while the remainder of the expression is otherwise identical to that found for the one-dimensional model. The two-dimensional expression for the screw volumetric discharge rate can therefore be written as

$$Q = F_d\,\alpha\,N - F_p\left(\frac{p}{\mu}\right)\left(\frac{dp}{d\lambda}\right) \qquad (8)$$

which is identical to the previous Equation 4 based on the function of the channel depth-to-width ratio. It can be seen that the retarding action of the flight faces on both simplified one-dimensional model except for the inclusion of the drag-flow and pressure-flow shape factors, F_d and F_p, respectively.

These factors are shown graphically in Figure 5 as a the drag and pressure flow increases as the screw channel becomes relatively deeper. It is sometimes convenient to picture the drag-flow shape factor, F_d, as a drag-flow pumping efficiency relative to a screw in which flight edge effects are absent. Thus, for example, it can be seen directly from Figure 5 that a screw having a channel depth-to-width ratio of 0.5 will convey fluid in drag-flow with an efficiency of 73% relative to the same screw with no flight edge effects.

The use of the shape factors F_d and F_p in Equation 8 provides a convenient but rigorous method for giving proper consideration to the flight edge effects when estimating screw discharge rates.

Partially Empty Screws

The two-dimensional extrusion theory just described has been extended in application to cover the situation of screws in which the channels are only partially filled with melt. Interest in vacuum extractor screws in particular has prompted investigations along these lines (2).

A sketch of a typical extractor screw is shown in Figure 6 along with a cross section of the partially-filled

channel. The differential Equation 5 for drag flow alone suffices to describe the flow in this situation since there can be no axial pressure build-up in a partially-empty screw section and, hence, no pressure flow. The boundary conditions used in arriving at a solution are different from those used for a full screw, however, since the fluid surface at $x = fw$ is now a free boundary where $\partial v_z/\partial x = o$ rather than being constrained by the trailing flight face.

The solution for the volumetric drag-flow rate in this situation can be derived from that previously obtained for a full screw as given by the first term in Equation 7. Note that the pumping efficiency of the full portion of a partially-empty screw is equal to that of a full screw whose channel width is *twice* the width of the fluid in the partially-empty screw, *i.e.*, equal to 2fw. This is true because of the symmetry of the velocity distribution illustrated in Figure 4 about the mid-plane where $\partial v_z/\partial x = o$. The pumping efficiency of the full portion of a partially-empty screw channel is thus given by the first bracketed term in Equation 7 with w replaced by 2fw.

The over-all pumping efficiency of the entire width of the screw channel (not just the full portion) can then be obtained by multiplying the pumping efficiency of the full portion, obtained as noted above, by f, the degree to which the screw channel is filled. Thus, the volumetric pumping rate of a partially-empty screw is given by

$$Q = \frac{Vhw}{2} \quad \frac{32}{\pi^3}\left(\frac{f^2}{(h/w)}\right) \sum_{g=1,3,5,\ldots}^{\infty} \frac{1}{g^3} \tanh\left[\frac{g\pi}{4f}\left(\frac{h}{w}\right)\right] \qquad (9)$$

Equation 9 can be written in the form

$$Q = F_d \alpha N \qquad (10)$$

where F_d is a drag-flow shape factor (or efficiency) which depends only on the screw dimensions and the degree to which the channel is filled with fluid. Comparison with Equation 4 shows that, as was the case for a full screw, the drag-flow corrected for edge effects can be expressed as that calculated from the one-dimensional theory multiplied by a correction factor, *i.e.*, the shape factor, F_d.

This drag-flow shape factor for partially empty screws is expressed graphically in Figure 7 as a function of the channel depth-to-width ratio and f, the fraction to which the channel is filled. The shape factor again has a convenient physical significance in that it can be interpreted as the pumping efficiency of the screw relative to the same screw running completely full and without flight edge effects.

There are several noteworthy points of interest in Figure 7. As the fraction to which the channel is filled increases, the pumping capacity increases, but when the channel becomes completely full and the trailing flight face contacts the melt, the pumping capacity abruptly drops to that value shown by the previous superimposed curve for a full screw. In other words, when operating a partially-empty screw in the region above the latter curve, this screw will actually pump at a *greater rate* than the same screw completely full of melt. This rather surprising situation can occur because the retarding edge effect of the trailing flight face is absent when the screw is not completely filled.

This situation could represent one cause for instability in the operation of a screw which is pumping against a very low back pressure. A "stick-slip" could conceivably occur along the trailing flight face that would cause the pumping capacity to oscillate between the top curve, which represents a full screw with the trailing flight face not wetted, and the superimposed curve for a full screw in which all channel surfaces are wetted by the fluid.

It should also be noted in Figure 7 that the pumping capacity of a screw increases more than proportionally as the channel becomes fuller. Thus, for example, with a channel depth-to-width ratio of 1.0, the pumping rate of an 80% full screw is about three times that of a 40% full screw, rather than twice as much as might be superficially inferred.

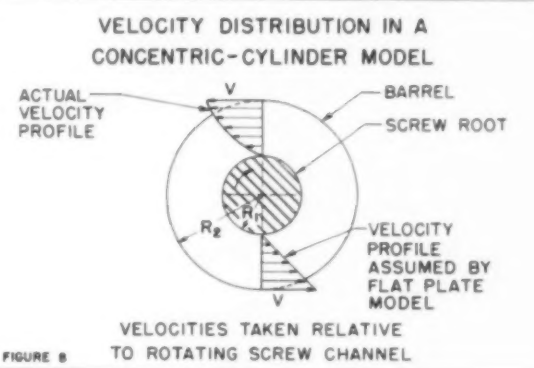


FIGURE 8

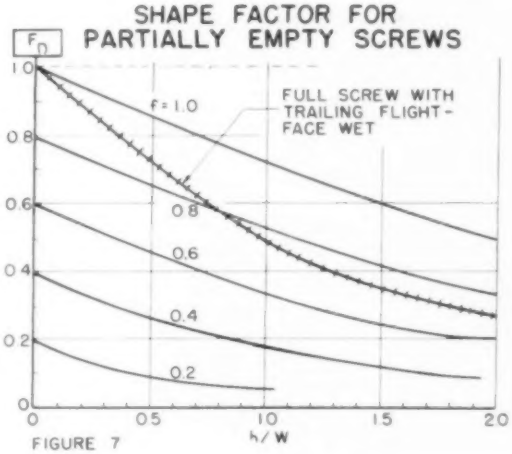


FIGURE 7

The use of Figure 7 in conjunction with equation 10 provides a simple technique for solving the design problems of:

1. What depth should a section of a given screw be made in order to pump at a given rate when operating at an established fraction full? Or conversely,

2. How full will a section of a screw operate when pumping at a rate established, for example, by a shallower up-stream metering section?

Correction for Screw Channel Curvature

A technique by which flight edge effects in deeper screws can simply but rigorously be accounted for has been developed and presented in the previous section of this discussion. One problem yet remains, however, *viz.*, that of taking proper consideration of the very fact that the screw channel is curved along a helical path rather than being flat as was pictured in the flat-plate model. The equations for flow based on the flat-plate model involved, as one of the included terms, a diameter. By virtue of the model that was assumed, however, no indication is given as to the proper diameter to use in the relationships based on this model. Crest, arithmetic mean, and, to a lesser extent, the screw root diameter have been variously employed in the literature. In deeper screws this factor assumes considerable importance.

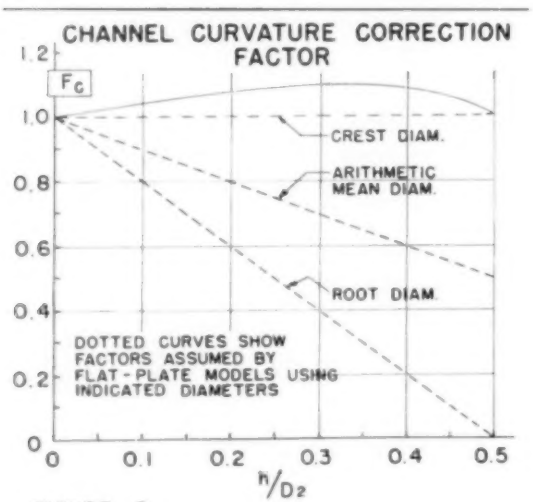


FIGURE 9

As an aid in obtaining an answer to this problem the screw and barrel can be pictured as being concentric cylinders as shown in Figure 8. Here, the screw is shown as rotating, but identical results are obtained if the barrel is assumed to rotate. If the flight helix angle is small, the motion of the fluid around the central cylinder approximates that of the fluid in the screw channel due to drag-flow.

The velocity distribution for this model system is well known and can be found in most fluid dynamics reference texts, for the model pictured here is basically a concentric-cylinder viscometer. The velocity of the fluid relative to the channel wall at the same depth is given by

$$v_z = 2\pi Nr \cos\phi \left[\frac{1 - (R_1/r)^2}{1 - (R_1/R_2)^2}\right] \tag{11}$$

If this velocity is now integrated across the channel area, an expression for the volumetric drag-flow rate can be obtained. Thus,

$$Q_d = nw \int_{R_1}^{R_2} v_z \, dr \tag{12}$$

which, upon substitution of Equation 11 and integration, leads to

$$Q_d = n\pi N w \cos\phi \left[R_2^2 - \frac{2 \ln (R_2/R_1)}{(1/R_1)^2 - (1/R_2)^2}\right] \tag{13}$$

If the flat-plate model drag-flow given by the first term in Equation 4 is now arbitrarily defined as being based on the *outside screw diameter*, it is possible by the use of Equation 13 to calculate a curvature factor, F_c, by which this flat-plate drag-flow can be multiplied to account for screw channel curvature. Thus, Equation 4 modified as described above to include F_c becomes

$$Q_d = F_c \alpha N \tag{14}$$

By making use of the identities

$$\alpha = \frac{\pi^2 D_2^2 h\left(1 - \frac{ne}{t}\right) \sin\phi \cos\phi}{2}$$

$$w = \left(\frac{t}{n} - e\right) \cos\phi$$

and equating Equations 13 and 14, it is found that

$$F_c = \frac{1}{2(h/D_2)} - \frac{\ln\left[\frac{1}{1 - 2(h/D_2)}\right]}{(h/D_2)\left[\frac{1}{\left(1 - 2\frac{h}{D_2}\right)^2} - 1\right]} \tag{15}$$

This approach is equivalent and preferable to that of calculating an effective mean diameter or channel depth since different mean values of the latter terms would be required for use in estimating the pressure flow in a curved channel.

The curvature factor, F_c, given by Equation 15 is dependent only on the ratio of channel depth to outside screw diameter. This factor is illustrated graphically in Figure 9. The curvature factor developed here is exact only for the limiting case of a zero helix angle. It is not unreasonable to assume, however, that the present result is at least a fair approximation to the true situaion encountered with screws of small helix angle where the flow is essentially circumferential. This drag-flow curvature factor can therefore probably be applied with little error to screws having a helix angle up to 17.7°, the angle corresponding to the frequently encountered "square pitch." In view of the proximity of the calculated curvature factor to unity and the known uncertainty which exists for finite helix angles, the use of a curvature factor of unity for screws of small helix angle can be justified

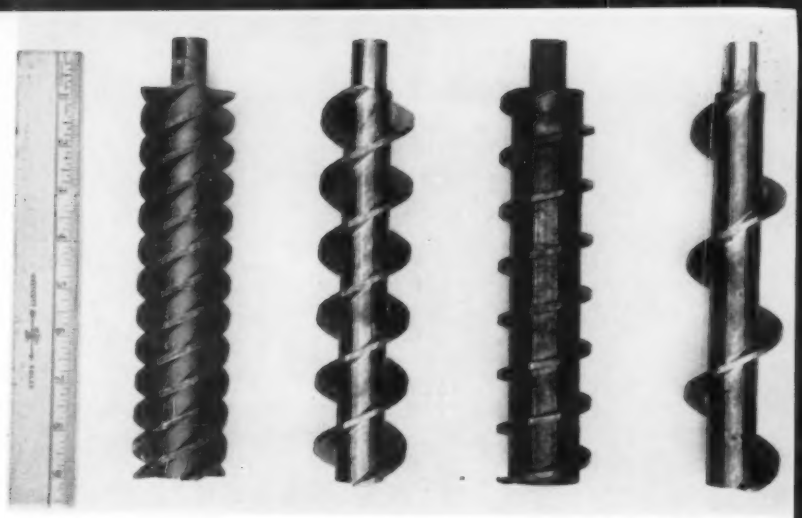


Figure 10. Two-inch Diameter Screws Used for Pumping Polyisobutylene.

on practical grounds until a more exact analysis for finite helix angles is available.

The fact that this curvature correction factor is greater than unity is quite significant. In effect, this states that the proper mean diameter to use in the flat-plate model drag-flow would be something *greater* than the outside screw diameter if this approach to the calculations were used. Intuition had previously led most workers to choose a diameter between that of the screw root and crest—usually an arithmetic mean diameter for the lack of something better.

Curves representing the channel curvature correction factor that, in effect, are assumed if the outside, arithmetic mean, or screw root diameter are used are superimposed on Figure 9 for comparison with the true curvature factor. At an h/D_2 ratio of 0.2, a typical value for the extraction section of a vacuum extractor screw, the error incurred in the pumping capacity by using an arithmetic mean diameter would be about 25%.

Summary

If both the channel shape and curvature factors are applied simultaneously, the extruder volumetric discharge rate equation may be written as

$$Q = F_c F_d \alpha N - F_p \left(\frac{\beta}{\mu}\right)\left(\frac{dp}{d\lambda}\right) \quad (16)$$

where

F_d = drag-flow shape factor given by Figures 5 or 7.
F_p = pressure-flow shape factor given by Figure 5.
F_c = drag-flow channel curvature factor given by Figure 9.

The screw geometric constants, α and β, are expressly defined as being based on the outside screw diameter as opposed to some mean diameter corresponding to an intermediate channel depth. (The existence of a clearance

$$\alpha = \frac{\pi^2 D_2^2 h\left(1 - \frac{ne}{t}\right)\sin\Phi\cos\Phi}{2} \quad (17)$$

$$\beta = \frac{\pi D_2 h^3\left(1 - \frac{ne}{t}\right)\sin^2\Phi}{12} \quad (18)$$

between the screw flight and barrel wall is not considered here.) Thus,

It should be appreciated that the drag-flow shape and curvature factors cannot rigorously be linearly combined and applied at the same time as has been done above, since the resulting Equation 16 can not simultaneously satisfy all of the conditions imposed during the development of these factors. In the absence of a more exact approach, there is practical justification for simultaneously applying the various factors. It is believed that the error thus incurred is small.

The influence of channel curvature in only the drag flow has been considered here. Analogous channel curvature effects exist for the extruder pressure flow. Establishment of these latter effects, preferably in the form of "pressure-flow curvature factors" is needed to round out our understanding of the pumping action of screw extruders.

Equation 16 for the output of a screw extruder is essentially as convenient to use as that based on the simplified theory, Equation 4, but yet does account quite rigorously for flight edge effects in both full and partially empty screws, and approximately for the effect of screw channel curvature. The convenience in use of Equation 16 eliminates the necessity for making a sharp distinction between the one and two-dimensional extrusion theories, since the essentials of both are contained and easily visualized in this one expression.

EXPERIMENTAL VERIFICATION

The volumetric pumping capacity of extruder screws having a wide range of channel geometrics has been investigated under conditions of no axial pressure gradient. The two-inch diameter screws illustrated in Figure 10 were among those used for pumping polyisobutylene; a conventional 2½ inch diameter, 15:1 L/D metering screw was employed while extruding branched polyethylene. In the latter case, the extruder was equipped with a valve die and pressure gauges along the barrel over the metering section. These permitted the adjustment of extruder operating conditions to compensate for pressure build-up

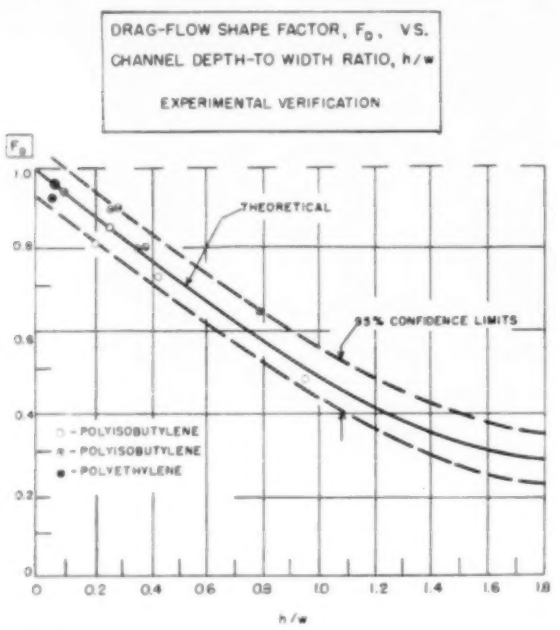


Figure 11.

in the feed section so that no axial pressure gradient resulted in the metering section of the screw. The screw helix angles ranged from 10 to 45°, and the channel depth-to-width ratio from about 0.04 to an extreme of 0.955, in which case the channel was approximately as deep as it was wide.

Data on the screw geometry, discharge rate, and screw speed were substituted into Equation 16 with F_c assumed equal to unity. Since the last term in this expression is zero under conditions of no axial pressure gradient, Equation 16 can be solved for the experimental drag-flow shape factor.

These experimental drag-flow shape factors are compared with the theoretical in Figure 11. The data illustrated are restricted to screws having a helix angle smaller than 23.8° with the exception of one point at an h/w of 0.076 where the helix angle was 30°. At a helix angle of 45°, the next largest angle available in the test screws, the experimental shape factors ranged about 30% low. These data are not shown in Figure 11. The assumption of a curvature factor of unity is apparently not valid with screws having a helix angle as large as 45°.

The good agreement between theory and experiment indicated in Figure 11 for a wide range of screw geometries provides verification of the theoretical drag-flow shape factor. These data also indirectly substantiate the validity of the curvature factor for screws having a shallow helix angle, and justify the choice of the outside screw diameter for use in the flow equations based on the flat-plate extruder model.

An experimental test of the validity of the pressue-flow shape factor is yet not available.

Acknowledgement

The writer gratefully acknowledges the benefit derived from discussions with J. C. Galt, Du Pont Engineering Department, on the subject of channel curvature correction factors.

Nomenclature

D = diameter
D_1 = screw root diameter
D_2 = screw crest diameter
e = axial flight width
F_c = curvature factor for drag flow
F_d = channel shape factor for drag flow
F_p = channel shape factor for pressure flow
h = screw channel depth
N = screw rotation speed
n = number of parallel screw flights
p = pressure
Q = net volumetric flow rate
Q_d = volumetric drag-flow rate
Q_p = volumetric pressure-flow rate
Q_t = volumetric transverse flow rate
R_1 = screw root radius
R_2 = screw crest radius
r = radial distance
T = component of relative barrel velocity in transverse channel direction
$= \pi DN \sin \phi$
t = flight lead
$= \pi D_2 \tan \phi$
U = circumferential component of relative barrel velocity
V = component of barrel velocity directed along the helix
$= \pi DN \cos \phi$
v = fluid velocity
w = channel width measured perpendicular to the flight faces
$= (t/n\text{-}e) \cos \phi$
x = distance measured perpendicular to flight faces increasing in the direction of transverse drag flow
y = distance measured from the screw root increasing outwards along the radius
z = distance measured along the helix in the direction of drag flow
α = drag-flow constant
β = pressure-flow constant
λ = distance measured along the screw axis increasing towards the die.
ϕ = helix angle measured at flight crest
μ = viscosity

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M. E. Bailey[1] and R. C. Kuder[2]

Allied Chemical Corp.

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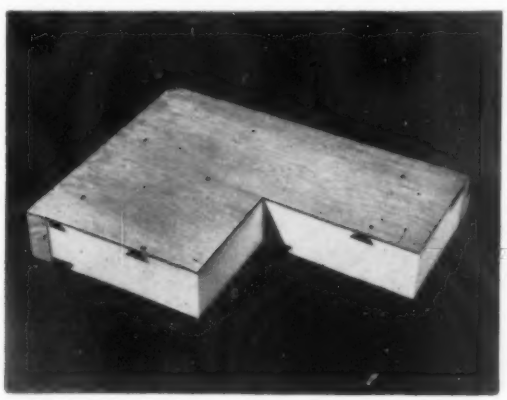
The **building, transportation, marine** and many similar industries which require materials possessing good structural strength, outstanding electrical and thermal insulating properties, lightness of weight and ease of production, are finding rigid urethane foams of particular interest. For example, a wall panel typical of what can be done is shown in Figure 1.

As more and more experience is gained using these foams in applications of this sort, it is expected that rigid urethane foams will become one of the most important applications of the urethanes.

Figure 1. Section of sandwich panel 85" x 58" x 4". Skins are 1/8" plywood and core is rigid urethane foam made in place under pressure.



The technology of these materials has as a raw material base compositions possessing isocyanate functionality together with compositions possessing hydroxyl and sometimes carboxyl functionality, as well as other materials, including water, catalyst and surface active agents. The manner in which these two principal materials are constituted is of fundamental significance to the successful formulation of a satisfactory foam. The choice of catalyst and surface active agent is also important.

Nacconate 1080H (National Aniline Division, Allied Chemical Corporation) is a modified tolylene diisocyanate especially designed for making rigid foams. PFR-6 (Barrett Division, Allied Chemical Corporation) is a polyester possessing carboxyl and hydroxyl functionality, and is also particularly suited for rigid foams. The more signifi-

Table I

Nacconate 1080H		PFR-6	
Isocyanate Equivalent	118-123	Acid No.	15-20
		Hydroxyl No.	465-495
Viscosity at 25°C.	150-200 cps.	Viscosity at 25°C.	70,000-80,000 cps.
		H_2O content	0.1 to 0.4%

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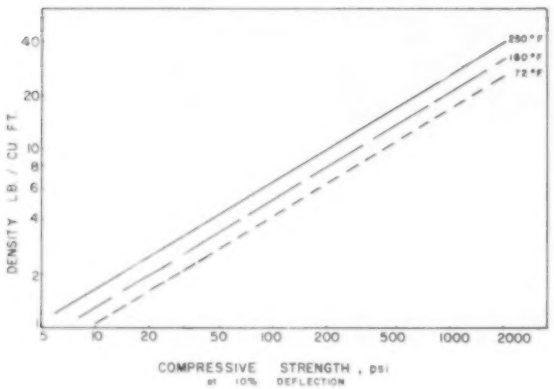
Figure 2. Load-bearing characteristics of rigid foams made from Nacconate 1080H and PFR-6.



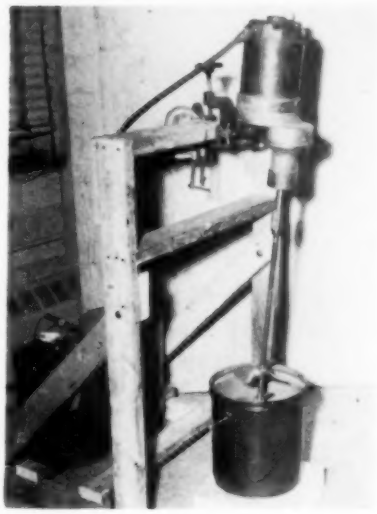


Figure 3. Portable mixer used to prepare the charge for a sandwich panel.

cant quality characteristics of these materials are as follows:

In the preparation of foam, the usual procedure is to mix the desired proportion of water, emulsifier and catalyst into the polyester as a master batch. The isocyanate is then added either batchwise or in suitable continuous mixing equipment and poured into the mold at once. Foaming begins in just a few seconds and is usually complete in a matter of a minute or so. The foam is set enough to handle in a few minutes; however, several days should elapse before the foam is subjected to stress, unless heat can be applied to hasten the cure. The following are typical foam formulations:

Table II

	Parts by Weight				
Polyester PFR-6	100	100	100	100	100
Nacconate 1080H	170	140	117	103	95
Water	4	2	1	0.35	—
Tween 21	1	1	1	1	1
N-methyl morpholine	1	1	—	—	—
Density, lbs./cu. ft.	2.0	3.3	5.0	10	15
Compressive strength, lbs./sq. in. at yield point	25	55	100	275	575

Variations in Density

The densities shown in the table are those obtained in an open mold (free blow). When foaming is done in a confined space, density values will tend to be higher. Variations in density are achieved by adjustments in amount of water and isocyanate. Changes in density have a profound change on the compressive strength of the foam, illustrated by Table II and Figure 2. The effect of temperatures up to 250°F. is also illustrated.

The amount of catalyst (N-methyl morpholine) may be varied between about ½ and 2 parts in order to regulate the rate at which foaming occurs. Other tertiary amines are suitable; dimethyl ethanolamine, N, N-dimethylcyclohexylamine and triethylamine tend to be faster than N-methyl morpholine; N-ethyl morpholine and N-coco morpholine tend to be slower.

In ordinary air, the resistance of these foams to distortion at elevated temperatures is excellent in comparison with other cellular plastics. For example, foams made on the formulations shown in Table II showed essentially no dimensional distortion on exposure to 230°F. for 24 hours.

Elevated Temperatures

Although direct experience of more than a few months is lacking, this elevated temperature test does suggest that these particular foams should show good dimensional stability at room temperature over considerably longer periods of time.

The foams also show good resistance to many other environmental influences. On the other hand, some agents attack the foams readily. (Table III).

Like other cellular plastics, these urethane foams are combustible. In general, the simple incorporation of ordinary fire retardants into the formulation in sufficient amounts to make the foams significantly better in this respect results in considerable tendency for shrinkage and other undesirable effects. However, recent developments in our laboratories have led to a formulation which gives a low-density foam which appears to overcome this deficiency.

Items 1 to 6 are thoroughly blended at room temperature to give a "premix". The Nacconate 1080H is added to the premix (when foaming reaction is desired) and mixed efficiently for 25-30 seconds. Then the mass is poured into the mold.

Table III

Resistance of Nacconate 1080H/PFR-6 Foams to Chemicals

Good Resistance	Fair Resistance	Poor Resistance
Benzene	Acetone	98% H_2SO_4
Toluene	Methyl ethyl ketone	
Gasoline	Ethyl acetate	(The foam is attacked immediately)
Motor Oil	(The foam is softened by these solvents, but recovers after drying)	
Carbon Tetrachloride		
5%-20% NaOH		
Concentrated HCl		
Acetic Acid		
Linseed Oil		
Glycerine		

The density obtained is 1.8 lbs./cu. ft. (in a closed mold). Compression resistance is approximately 20 to 25 psi at 16 to 20% deflection. No significant dimensional distortion is noted below 230°F.

To test the resistance of urethane foams to fire, blocks 4" x 4" x 1" were placed on an asbestos sheet 6" x 6" containing at the center a hole 2 cm. in. diameter. A microburner with a flame 1" high was arranged on a pivot so that the tip of the flame just touched the under surface of the foam when the burner was swung into place to start the test. The foams were exposed to the flame until the tip was visible at the top surface of the foam. Results of this test are in Table V.

Mixing

This particular formulation is easy to handle and lends itself to manipulation on a large scale. Mixing can be done by machine; however, a drum and a Lightning mixer are adequate (Figure 3).

Table IV

		Parts by Weight
1.	Polyester PFR-6	100
2.	Celluflex CEF (Tris-Beta chloroethyl phosphate)	50
3.	Water	10
4.	N-methyl morpholine	1
5.	Tetrahydroxyethyl ethylenediamine	2
6.	Tween 21	1
7.	Nacconate 1080H	275

Table V

Type of Foam	Time to Burn Through	Flammability of Foam
Foamed Polystyrene (Fire Retardant type)	15 seconds	Foam caught fire; had to be extinguished
Castor oil-based urethane foam	35 seconds	Self extinguishing when flame was removed
Rigid urethane foam containing fire retardant	265 seconds	Self extinguishing when flame was removed

The ingredients require about 25 seconds for mixing. They are poured at once into the mold (Figure 4). For example, the wall panel in Figure 1 was made by pouring the foaming mixture into a plywood shell held in a horizontal position in the jig shown in Figure 5. The mold is closed, the jig is clamped in place and held for about twenty minutes. The panel can then be handled; however, a few days should elapse before the panel is subjected to service.

Similar structural members can be made using other skin materials. Polyester-fiber glass laminates and aluminum are particularly useful. Application for rigid foam in structures such as these is already found as door and wall paneling. Still wider use should be seen in the very near future. ★ ★

Figure 4. Pouring the charge for a sandwich panel.

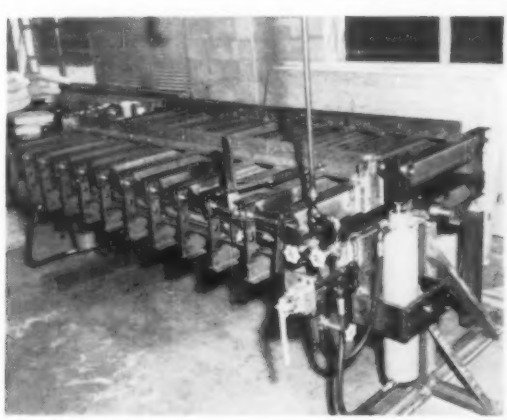


Figure 5. Jig for holding the sandwich panel under pressure while the foam develops and sets.

ENCAPSULATING AIRBORNE ELECTRONICS

By incorporating flexibility into the normally hard unmodified epoxy resins, encapsulating materials with high thermal and mechanical properties are obtained.

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EXPERIENCE in the last ten years has shown that an ideal encapsulating or potting system must completely protect components and equipment over a wide temperature range. The components must be protected from electrical and mechanical breakdown due to moisture, vibration, corrosion, chemical attack, fungus, thermal and mechanical stress. Developments in aircraft and missiles introduce rigid and exacting performance requirements for encapsulating materials. An ideal material must be capable of withstanding temperatures of −80°C to 200°C under conditions of extreme mechanical loads. Electrical performance must be maintained during the life of the electronic systems. Epoxy resins possess most of these properties.

New resin developments where flexibility is incorporated into the normally hard, unmodified epoxy resin, promise to give the design engineer a new tool with which to work. Flexibility has been achieved by the addition of reactive plasticizers, such as trimer acids, to basic epoxy resins. Heat aging tests indicate that this type of reactive plasticizer is bound stably into the molecular structure of the polymer. Mechanical and electrical properties show little change through the life of the system. Weight loss of castings made from this type of resin are less than 6% after 2,000 hours heat aging at 175°C.

The heat aging tests referred to in this report are actually thermal cycling tests. Test specimens were ¼" by 4" by 4" cut from sheets prepared by standard casting techniques. Weight loss was determined by weighing the test specimens at room temperature after every 312-hour cycle of exposure at 175°C or 200°C. Tests were continued for 20 cycles, or 6,240 hours. Data obtained from weight-loss measurements can be used to evaluate the heat stability of various resin systems. Low weight losses after long term aging at elevated temperatures indicate thermally stable materials. High weight-loss systems fail due to severe embrittlement or cracking. Electrical properties improve with aging until mechanical failure, at which time electrical failure occurs.

Thermal shock tests are usually performed on electronic assemblies which have not been heat aged. These tests determine whether a system meets initial thermal shock requirements. In order to obtain more life information on the encapsulated components, systems should be aged at elevated temperatures and re-run through the thermal shock test. Under these conditions low weight loss systems show greater abilities to retain their thermal shock resistance than high weight loss systems. An ideal encapsulating compound will maintain good thermal shock resistance throughout the life of the system.

Typical mechanical and electrical properties of rigid epoxy systems, amine cured and acid anhydride cured, are given in Table I. Epoxy trimer acid systems are listed in Table II.

Airborne transformers, small, medium and large, have successfully been encapsulated and potted using epoxy trimer acid resin systems. These transformers have passed the full requirements of MIL-T-27A specification, including thermal shock. The temperature range of thermal shock included the range of -55°C to 155°C. In addition to passing the initial thermal shock test, these transformers were aged at 175°C and successfully re-run through thermal shock. Epoxy trimer acid systems can be cured at temperatures as low as 75°C. Temperature-sensitive networks, including transistor circuits, can be potted with this system without damage to components.

Airborne cable harness assemblies have been potted for many years with various plastics and synthetic rubber compounds. Most of these materials have been limited to 250°F operation. The evolution of faster flight with accompanying aerodynamic heating has pushed up the temperature requirements for airborne potting compounds. Epoxy trimer acid flexible potting formulations have been successfully used in harness and connector applications at temperatures to 350°F.

Copolymers of epoxy resins and silicone resins produce flexible and resilient polymers with outstanding heat resistance, electrical and physical properties. Epoxy-silicone copolymers have been developed especially for the encapsulation of electronic systems where temperatures in the 200°C range are encountered in combination with high mechanical stress.

Heat aging tests indicate that the epoxy-silicone material will perform at least 6,000 hours at 200°C. The weight losses of castings made from this system are 2.1% after 1,000 hours at 200°C, 5.1% after 2,000 hours, and 16% after 6,000 hours. Volume resistivity after 6,000 hours at 200°C is 3.3×10^{15} ohms-cm measured at 25°C. Further mechanical and electrical data is presented in Table III. The epoxy-silicone copolymer is a two-component, 100% solids, high viscosity liquid system. The resin can be handled easily by following currently accepted encapsulation procedures. Water absorption on epoxy-silicone systems is appreciably lower than straight silicone resins. A typical cure schedule would be: 4 hours

at 130°C plus 2 hours at 180°C. Elongation of fully cured castings is 10%. Initial linear shrinkage is 1.54%.

Transformers have been successfully encapsulated in this epoxy-silicone copolymer and passed the requirements of MIL-T-27A. These transformers are intended for Class H and operated at 200°C.

Many types of airborne electronic equipment and components have been encapsulated successfully in epoxy resins. Rotating devices have been a severe design problem. Strains caused by different rates of thermal expansion of construction materials have ruptured insulation. The use of flexible resins has reduced failures due to this condition. Modern advancements in new types of magnetic materials have helped the miniaturization trend in electronic equipment. Some of these special magnetic materials are pressure sensitive. The use of flexible potting materials tends to minimize potting strains and produce minimum electrical shifting.

Many special electronic components make use of deposited conductive films to obtain a specific resistance or capacitance. Delay lines are a typical example. Some rigid epoxy systems have a tendency to distort or dislocate these deposited films. Flexible epoxy potting compounds produce minimum changes in the potted components.

Conclusion

Flexible epoxy resin systems have been developed which protect electronic components over a wide temperature range. Flexibility must be incorporated into the epoxy system in such a manner that the flexibilized system will maintain its physical and electrical properties after long-term service. Epoxy trimer acid systems meet all of these requirements. Thermal shock requirements of -55° to 155°C have been met with these systems. Thermal cycling tests have been successfully performed from -65°C to 175°C.

Epoxy-silicone copolymers also meet the specified requirements. These systems are thermally stable at 200°C. Thermal cycling tests of more than 6,000 hours at 200°C have been run successfully on these systems.

Many airborne electronic devices have been potted in epoxy trimer acid polymers, and epoxy-silicone copolymers. Airborne transformers have been encapsulated and have passed the requirements of MIL-T-27A, including thermal shock. The modified epoxy resins, where flexibility can be obtained without the sacrifice of heat stability and mechanical strength, are a definite advancement towards the design engineer's goal for an ideal encapsulating material.

TABLE I
Typical Rigid Epoxy Systems

	Filled Epoxy Amine Cured	Filled Resilient Epoxy Anhydride Cured
Dielectric constant (1 Mc at 25°C)	3.3	3.4
Dissipation factor (1 Mc at 25°C)	.027	.014
Dielectric strength	>400 volts/mil	>400 volts/mil
Volume resistivity (at 130°C initially)	5×10^{16} ohms-cm	5×10^{16} ohms-cm
Volume resistivity (at 130°C after 3,000 hrs aging at 175°C)	1×10^{15} ohms-cm	2×10^{12} ohms-cm
Izod impact	.16 ft-lbs/in	.36 ft-lbs/in
Tensile strength	6,000 psi	8,000 psi
Linear shrinkage	0.6%	0.76%
Weight loss (1,000 hrs at 175°C)	1.2%	1.8%
Weight loss (2,000 hrs at 175°C)	2.3%	3.1%
Weight loss (3,000 hrs at 175°C)	Failed by cracking	4.2%
Weight loss (1,000 hrs at 200°C)	Failed by cracking	15.5%
Weight loss (2,000 hrs. at 200°C)	Failed by cracking	20.5%
Weight loss (3,000 hrs at 200°C)	Failed by cracking	Failed by cracking

TABLE II
Typical Flexible Epoxy (Trimer Acid System)

	Filled Epoxy Trimer Acid System
Dielectric constant (1 Mc at 25° C)	3.11
Dissipation factor (1 Mc at 25°C)	.0220
Dielectric strength	>400 volts/mil
Volume resistivity (at 130°C initially)	1.6×10^{17} ohms-cm
Volume resistivity (at 130°C after 500 hrs aging at 175°C)	2.1×10^{12} ohms-cm
Izod impact	>4 ft-lbs/in
Linear shrinkage	0.8%
Tensile strength	2,500 psi
Elongation	39%
Weight loss (1,000 hrs at 175°C)	3.7%
Weight loss (2,000 hrs at 175°C)	4.1%
Weight loss (3,000 hrs at 175°C)	5.0%
Thermal shock, MIL-T-27A (–55°C to 155°C)	Passed
Thermal shock, MIL-T-16923B, Types A, B and C (-55° to 130°C)	Passed

TABLE III
Typical Epoxy (Silicone System)

	Filled Epoxy Silicone System
Dielectric constant (1 Mc at 25°C)	3.43
Dielectric constant (1 Mc at 200°C)	4.50
Dissipation factor (1 Mc at 25°C)	.008
Dissipation factor (1 Mc at 200°C)	.047
Volume resistivity (at 25°C initially)	5×10^{15} ohms-cm
Volume resistivity (at 25° C after 6,000 hrs exposure at 200°C)	3.3×10^{15} ohms-cm
Linear shrinkage (after 3 hrs at 180°C)	1.54%
Linear shrinkage (after 240 hrs at 200°C)	2.19%
Tensile strength	6,000 psi
Elongation	10%
Weight loss (1,000 hrs at 200°C)	2%
Weight loss (2,000 hrs at 200°C)	5%
Weight loss (3,000 hrs at 200°C)	9%
Weight loss (6,000 hrs at 200°C)	16%

New Epoxy Resins

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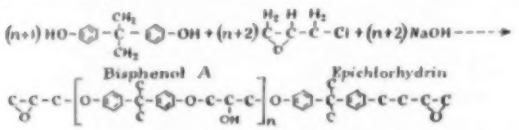
Division, The Borden Co.

Epoxy resins as commercially available structural plastics are only about six years old and have already wrought many changes in the reinforced plastics, electrical, tooling, and foundry industries.

All who are familiar with epoxy resins probably know the standard resin as the bisphenol A type since it is the basis of about 95% of current epoxy production. The standard method of preparation involves the condensation of bisphenol A with epichlorhydrin in the presence of caustic.

Figure 1. Bisphenol A Epoxies.

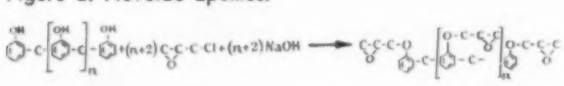


The advantages of low shrinkage, excellent adhesion, good cure at room temperature, and superior electrical properties are well known, but it has been evident for some time that it is not a cure-all. Some of the problems presented by this resin have included poor heat stability, comparativly high viscosity, crosslinking through the converter rather than through the resin base (bisphenol A epoxy resins are difunctional when reacted with amine converters) and, probably most annoying in the tooling and foundry industries, close control of the resin-converter ratio in order to obtain maximum properties. Unlike polyester resins which can be cured catalytically, the bisphonol A resins not only require the proper amount of converter in the resin, but must be thoroughly mixed together in order to obtain proper results. There has been much work on creating new resins which might alleviate some of the problems inherent in these resins. Most of this new work has been centered about three basic types: novolac epoxies, glycerine epoxies, and peroxide epoxies.

Novolac Epoxies

The novolac epoxies are similar to the bisphenol A epoxies, but instead of the phenol-acetone dimer base, a phenol formaldehyde condensation product is used.

Figure 2. Novolac Epoxies.



Some of the advantages of using this polyfunctional resin are:

1. Crosslinking with amine cures can occur through the resin base due to its polyfunctionality.
2. Good heat stability result due to the greater degree of crosslinking and high aromatic density.
3. Because of the higher epoxy functionality per molecule, the converter ratio is not as critical as in the bisphenol A resins.
4. There are unlimited possibilities as to base resin configuration which theoretically can lead to even higher strength resins.

The disadvantages to date seem to be:

1. It usually has a higher viscosity.
2. Too much crosslinking can yield a brittle material unless proper converters are used.

Examples of the properties obtainable with novolac epoxies can be seen by comparing a representative experimental resin of the novolac type with a standard high temperature phenolic laminating resin (American Reinforced Plastics Company).

Table I

Ultimate Flexural Strength (PSI)

	70°F	300°F	500°F
Novolac Epoxy (1)	67–80,000 (3)	49–56,000	25–30,000
CTL-91LD (2)	60,000		40,000

(1) 181-Volan A glass fabric
(2) 181-114 glass fabric
(3) Depending on converter used

Another example of the higher heat resistance of the novolac epoxies can be seen in the data released by the Dow Chemical Co. and presented by Partansky and Shrader in 1956 at the American Chemical Society meeting.

Table II

ASTM HEAT Distortion Temp. °C.

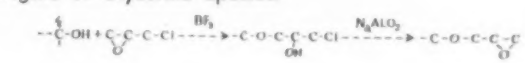
Curing Agent	Epon 828-C	Epon 828-P	E.N.-2.6	E.N.-3.2
TETA*	124	128	152	
MDA**	155	168	198	203
60/40 MPDA/MDA***	161	161	190	200
Chlorendic Anhydride	183	196	210	

**Triethylene Tetramine Methylene Dianiline*
****Metaphenylene Diamine/ **Methylene Dianiline*

Glycerine Epoxies

This material is prepared by an initial addition reaction between epichlorhydrin and subsequent dehalohydrogenation by means of a base.

Figure 3. Glycerine Epoxies.

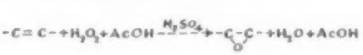


The product has a very low viscosity, is essentially colorless and yields a more highly crosslinked structure but unfortunately, due to the aliphatic backbone and unreacted hydroxyl groups, reacts with an amine to give a material which exhibits comparatively poor heat and water resistance as well as poor physical properties. Also of importance is the fact that the resin has a higher cost due to more expensive processing. It has found some utility as a diluent for Bisphenol A epoxies, and in treatment of fibers.

Peroxide Epoxies

There has been a great effort expended in creating resins suitable for structural application utilizing this process, but to date there has been none available for commercial sale. Potentially this method could be an approach to low cost epoxies since theoretically almost any molecule containing an olefinic group is capable of being transformed into an epoxide. The simplest method of preparation calls for the epoxidation of unsaturated groups by means of an organic acid and hydrogen peroxide.

Figure 4. Peroxide Epoxies.



The process, although seemingly simple, has many problems which have prevented its exploitation except in the field of stabilizing-plasticizers for chlorinated polymers such as polyvinyl chloride.

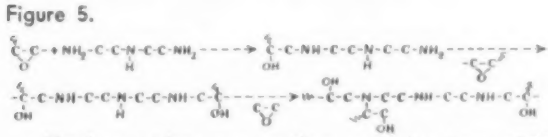
Converters for Epoxy Resins

A. Room Temperature Converters

Probably the most widely used converters for epoxy resins are the primary and secondary polyalkylene polyamines characterized by diethylenetriamine (DETA). Triethylenetetramine (TETA), and Tetraethylenepentamine (TEPA). These amines yield far better room temperature cures than any of other converters but unfortunately are prime causes of dermatitis in many individuals and as a result must be handled with utmost caution.

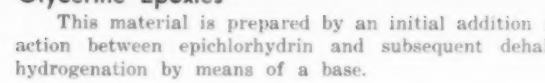
The reaction mechanism of the polyamine indicates its action as a crosslinking agent.

Figure 5.



Tertiary amines are another converter type which can yield room temperature cures. Here, however, the amine seems to act only as a catalyst. The reaction mechanism shows how the conversion is believed to progress. (L. Shecter & J. Wynstra, I. & E. C., 48, 86-93, (1956).

Figure 6.



These tertiary amines tend to create brittle materials with comparatively poor electrical and adhesive properties. A prime example of such a tertiary amine is DMP-30 (Rohm and Haas).

There are many converters which combine the primary, secondary and tertiary amine groups within their molecular structure and in general create converted resins with a variety of properties.

Recent Interest

Recently a great deal of interest has been created about minimum toxicity converters. These new converters can be any of four types:

1. Hydroxyalkylated polyamines:

Work conducted at the Bakelike Company laboratories ascertained that the reaction product of a very low molecular weight monoepoxy and diethylene triamine reduces the dermatitic toxicity to a very low point. It seems that the effect of hydroxyl groups on the polyamine structure tends to inactivate the dermatitic effect without appreciably reducing their conversion characteristics.

2. Cyanoalkylated polyamines:

These materials show good cure properties but are still in the laboratory development stages. In both these and the hydroxyalkylated polyamine conversions there is some sacrifice in physical properties.

3. Polyamine adducts:

A reaction product between the base epoxy resin and an excess of polyalkylene polyamine. These materials exhibit excellent cures at room temperature since they are a prereacted material with essentially the same ingredients as the normal resin-amine cures. Unfortunately the commercially available adducts which are odorless and non-dermatitic have a very high viscosity which make them unsuitable for casting and potting applications.

1. Amine Terminated polyamides:

This is a reaction product which may be prepared from dimerized linoleic acid and excess diethylene triamine. When combined with epoxy resins in proper quantity they yield good room temperature cures with excelle··t impact resistance but reduce the good heat distortion properties which can normally be expected utilizing polyalkylene polyamines.

B. Elevated Temperature Converters:

1. Basic:

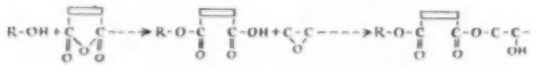
These compounds are generally the aromatic polyamine type and their purpose is to yield conversions with better properties and/or handling characteristics than that which can be obtained from room temperature converters. Whereas the room temperature curing polyamines of necessity have short working life, the heat curing ones have more than adequate pot life. Descriptive of the general type are metaphenylene diamine, 4,4' diamino diphenyl, methane, 4,4' diamino diphenyl sulfone Catalyst Z (a mixture of aromatic polyamines (Shell Chemical Co.), and low molecular weight aniline-formaldehyde resins. The problem with most of the aromatic polyamines (Catalyst Z is an exception!) is that they must be melted before mixing, and the resin must be heated to keep the converter melted while mixing. This naturally reduces the working life and creates production problems. The maximum heat stabi-

lity which can be expected from these converters and Bisphenol A epoxy resins is on the order of 160°C.

Two high temperature converters of the amine type which do not fit into the above category are boron trifluoride complexes and Dicyandiamide. Both are extremely stable at room temperature and can be considered latent converters which decompose on heating to 180C°., creating extremely active systems. The reaction of Dicyandiamide is not fully understood but the BF_3-amine salt upon decomposition becomes free boron trifluoride, an extremely active acid catalyst. It does not produce good adhesive properties however, probably because of the absence of many hydroxyl groups in the cured resin product. It does create cured polymers exhibiting good physical properties and excellent chemical resistance.

2. Acidic:

The most used acidic converters for general purpose use are the acid anhydrides, one of the very few converter types which react with both the hydroxyl and epoxy groups of the epoxy resin. The reaction mechanism shows its mode of reaction:



Due to their high stability and tightly cross-linked structures, they can yield extremely high heat resistance and because of their inherent minimum dermatitic nature, hold promise for heat cured high temperature structural plastics. Another reason for consideration is the fact that there is practically no exotherm in large masses. This, of course, makes them naturals as converters for large castings and plastic tools. Unfortunately they require high temperature plus long postcure to effect a maximum cure, but it is known that small amounts of base will help to catalyze the reaction.

The acid anhydrides can be divided into two categories:

a. Liquid anhydrides, with melting points less than 40°C.:

These converters are easily mixed into the resin and yield an almost infinite pot life. The maximum heat distortion properties with bisphenol A resins is about 140°C, but because of the low viscosity and extremely good mositure resistance, might find extended application in the electronics industry as encapsulating materials. Unfortunately they have not as yet yielded physical properties high enough for consideration as structural converters. Examples of this type of converter are dodecenyl succinic anhydride, hexahydrophthalic anhydride, and monochloromaleic anhydride.

b. Solid anhydrides:

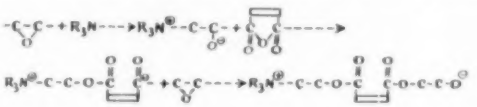
These converters are characterized by a requirement similar to the aromatic amines, namely that the resin must be heated in order to properly mix in the powdered converter. Again the cured physical properties show a reduction over that of amine converted systems but mixtures of pyromelletic dianhydride and maleic anhydride have yielded heat distortion temperatures as high as 260°C. Examples of this type of converter are: Phthalic Anhydride, Pyromelletic dianhydride, Maleic anhydride, Chlorendic (HET) anhydride and mixtures thereof. An interesting phenomenon is the fact that Chlorendic anhydride decomposes above 180°C., liberating chlorine, a fact which may explain why this anhydride gives resins with excellent fire retardant properties.

Accelerators for Epoxy Converter Systems:

1. Anhydrides:

A few years ago, it was discovered that the addition of small amounts of tertiary amine to a system utilizing anhydride conversion reduced the cure time and temperature.

The reaction mechanism is believed to be as follows:



2. Amines:

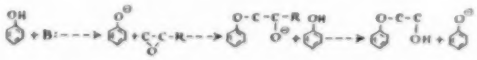
A. Phenol

Phenol added to an epoxy resin accellerates the rate but reduces the viscosity and heat distortion temperature.

Epiphen 845

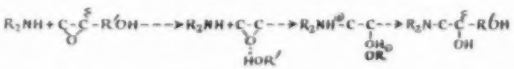
phr Phenol	0	5	10	20
Viscosity 25°C. (cps)	4900	3300	2600	800
gel time (min) (100 g. mass)	10	7	5	2
Max exothern °C.	320	280	316	
Ult Flex Strength (psi)	20,800	20,900	19,000	17,000
Ult Flex Modulus (psi)	437,000	456,000	395,000	400,000
Heat Distortion Temp (°C.)	88	64	59	52
Barcol Hardness	87	86	89	89

The reaction mechanism between the phenol and epoxy using amine onverters is thought to be as follows.



B. Alcohols

It was found that small amounts of alcohol added to the reaction also acted as an accelerator with the following mechanism. (L. Schecter & J. Wynstra, I. & E. C., 48, 86-93 (1956). Figure X.



One can understand from this how the hydroxyalkylene polyamines actually yield shorter pot life and accelerated cures.

Resin Specifications

Many engineers and people working with epoxy resins sometimes wonder just what meaning a manufacturers specifications have. In epoxy resins, this is also true and it might be worthwhile to cover those relating to epoxy resins.

The most important specifications of interest to the plastic tooling industry and specific to epoxy resins is the epoxy value or equivalent weight. This term usually expressed in grams/mole, indicates the relative reactivity of the molecule. A Bis-phenol A epoxy resin which is fully epoxidized and has not reacted with itself can theoretically attain an epoxy value of 170. Any epoxy value higher than this indicates that some of the active

(Please turn to page 40)

HIGH-TEMPERATURE EPOXY RESINS FOR REINFORCED PLASTICS

J. M. Thomas
Jones-Dabney Co.
Louisville, Kentucky

In opening the discussion of the application of epoxy resins to reinforced plastics for use at high temperatures, it is somewhat difficult to determine a starting point. The field is very broad, including as it does the combined variables of time and temperature against which a whole host of physical and electrical properties must be plotted. In applying the epoxies to this field, we are working with materials which are characterized by their tremendous versatility with regard to properties, formulation variables and compatibility.

In order to organize the discussion, the intention is first to discuss the behavior of the basic liquid, 100% nonvolatile epoxy resin which is essentially the diglycidyl ether of bisphenol A. This material has two epoxide groups per molecule which gives it a functionality of from two to four, depending on the method used for curing. With respect to thermal decomposition, polymers of this molecule are stable to temperatures in the vicinity of 500°F., and at higher temperatures decomposition may be slow enough to allow use depending on the service life desired. Since the epoxy resins have the inherent thermal stability necessary for use in this temperature range, the problem is to develop formulations which yield the desired physical and electrical properties under the specified conditions.

The curing of such resins for use in high temperature laminates can be accomplished with a number of curing agents. Let us list a number which have been used, with the flexural strengths which have been obtained:

Table I

Curing Agent	Flexural Strength (PSI)		
	Room T.°	300°F.	500°F.
Dicyandiamide	80,000–90,000	10,000	
Metaphenylene diamine	70,000–80,000	50,000–60,000	5,000–12,000
Diamino diphenyl sulfone	80,000–90,000	50,000–65,000	8,000–15,000
(1) Chlorendic anhydride	80,000–90,000	40,000–80,000	8,000–10,000
(2) Pyromellitic dianhydride	75,000–85,000	50,000–60,000	12,000–40,000

Necessarily the above are rough figures, assembled from many sources without regard to many variables such as curing, aging at temperature and resin content, but they are indicative of a trend. At the moment it is our belief that PMDA is capable of yielding a cured epoxy resin with better physical characteristics in the neighborhood of 500°F. than can be obtained by any other curing agent.

For a given resin there is an optimum amount of a given curing agent for securing the best high temperature properties. This is not necessarily the amount which will result in the best low temperature characteristics. The higher the temperature the more critical the ratio and the more rapidly properties fall off as that ratio is varied. Since this is so, it is of the utmost importance that both resin and curing agent be controlled within narrow limits or the ratio varied according to variations in reactive groups. The presence of trace elements or compounds can change performance characteristics in either direction. Laboratory work is under way in this field and may result in the recommendation that controlled amounts of certain trace materials be added prior to curing.

So far we have discussed methods of obtaining high temperature performance using conventional epoxy resins. We now must consider changing the resin composition. This has been done by blending epoxy resins with phenolic resins to obtain some very promising results. Another approach and perhaps a more fruitful one is by varying the basic raw materials from epichlorohydrin and bisphenol A. A major step in this direction was the introduction of X-131 resin by Shell Development Company. They have published figures indicating flexural strengths from 7,000 to 38,000 psi at 500°F., and these figures have been verified in our laboratories. There are a number of other polyhydric phenols currently being evaluated which have excellent prospects of finding high temperature applications in new epoxy resins. At this time a word should be said about new techniques for introducing the epoxide ring into almost any molecule which has a carbon—carbon double bond. So many new epoxy materials are available in experimental quantities due to these processes that applications may well be found in any field.

Table II

Resin Type	Room T.°	300°F.	500°F.
Shell X-131	65,000–80,000	50,000–60,000	7,000–40,000
Epoxy-Phenolic Combination	70,000–80,000	50,000–60,000	10,000–40,000

In addition to the infinite number of possibilities in epoxy resin composition which are being evaluated so painstakingly by our laboratories, as well as the laboratories of other companies, there is an equal or greater effort in the field of curing agents. Add this to the already indicated marriage of the epoxy resins and phenolics and/or silicone resins and some idea of the complexity of this field can be obtained. The reinforced plastics people are better able to take advantage of this versatility since they are capable of using the resins in solvent solutions.

Just as the use of fillers at room temperature may change such properties as expansion coefficients, heat conductivity, hardness, flexibility, chemical resistance, etc., so at high temperatures can they change the properties of any given resin system. In addition, the strong tendency toward oxidation at temperatures over 500°F. strongly indicates the use of antioxidants or other additives which promote stability. Since we are primarily resin producers, our studies in this field are not extensive and I am sure many users of epoxies are more qualified to speak of this.

During this discussion it has been pointed out that epoxy resin formulations are presently available which have service applications at temperatures in the neighborhood of 500°F. Unfortunately, many of these systems are very difficult to handle on a production basis, and considerable effort is currently being expended in order to develop procedures, methods, or modifications in formulation which will retain the high temperature properties and still allow the use of economically feasible production methods. As we contact various potential users of epoxy resins we are amazed at the properties that can be obtained. It is our feeling that the use of these resins in reinforced plastics applications is now reaching the stage where the application of substantial volumes in the high temperature reinforced plastic field is just around the corner. Development programs in many industries are about to bear fruit. This does not mean that development work in the basic resins will cease. Certainly there is a tremendous field to cover, and the promise of superior resins is not an idle one. As new basic raw materials are available in production quantities, these resins will be introduced where they seem to have application. Certainly the mechanism of curing epoxy resins lends itself very well to high temperature applications. The stability of the bond, the lack of evolution of gas, and the thermal stability of the basic molecule all indicate a very optimistic future for these materials. We are very enthusiastic and are extremely interested in cooperating closely with those of you who are working in the field of application. ★ ★

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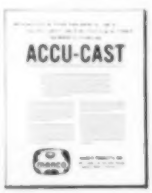

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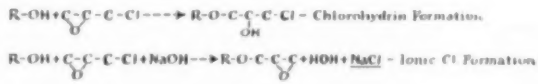
Epoxy Resins . . .

(Continued from page 38)

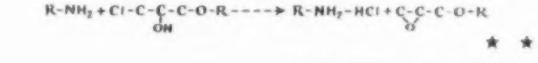
epoxy groups have disappeared, either to make higher viscosity materials or because of a side reaction. Although theoretically possible, it has been very difficult to obtain this low an epoxy value. The usual epoxy equivalent weight of the standard low viscosity resins ranges between 185 and 200. As the epoxy value rises, the resin usually increases in viscosity until it becomes solid at an epoxide value of about 240. This pertains only to bisphenol A resins since novolac and glycerol epoxies can theoretically attain epoxy values of 159 and 86 respectively.

The second specification of importance is the chlorine content, usually expressed in %. This chlorine value, contrary to popular belief, is not an indication of the amount of free epichlorhydrin remaining in the resin, but ordinarily is the sum of the residual ionic salt formed during the manufacturing reaction, and the organic chlorine not completely removed which is present as chlorohydrins.



This specification is important to the electronic and electrical industries since the chlorine can lead to poor electrical characteristics, but they are not important in plastic tooling where the presence of chlorine in the resin, either ionic or organic, does not seem to impare the cured physical properties of the resin. This is probably due to the fact that the organic chlorine in the presence of base converter actually is eliminated in the form of HCl causing the formation of a new epoxy ring which can further react.

The HCL forms a salt with the base which renders it inactive.



★ ★

George S. Indig was born in Bronxville, N. Y., in 1925, and attended Roosevelt High School in Yonkers. After serving in the U.S. Army during World War II, he studied at Princeton University where he received the B.S. degree in chemical engineering in February 1947. He was awarded the LL.B. degree by Columbia University in June 1949.

As a member of the patent staff of Bell Telephone Laboratories since January 1950, he has specialized in patent work relating to chemical and metallurgical inventions.

George S. Indig

PATENT LAW —
How the plastics engineer can apply it

A PATENT IS a contract between an inventor and the Government under which the inventor makes a complete disclosure of his invention in exchange for which the Government gives the inventor the right to exclude others from using his invention for a period of 17 years. The value of the patent system in a democratic society is apparent: The published disclosure is available to all interested persons, thereby increasing technological progress. The patent right itself gives sufficient protection to industry to attract capital in the constant search for new improvements and in the commercial development of the invention.

Patents may be obtained on any of various categories of invention, notably: (1) compositions of matter, (2) methods or processes, (3) machines or apparatus, and (4) articles of manufacture. Composition of matter include chemical compounds as well as mixtures. Examples of the other three categories in the order set forth are an anionic method of making polyethylene, a new distillation apparatus, and an article having a certain configuration, as a squeeze bottle made of polyethylene.

Aside from certain statutory exceptions including processes applicable only to the production of fissionable materials, the only category of scientific advances which are not patentable, are those which have no physical embodiment. For this reason, a mere idea or mental concept, as a method of doing business, is not patentable.

Assuming that a development falls within a patentable category, it is next necessary that it be possessed of certain essential elements to be patentable. Briefly these elements are novelty, inventiveness, and utility. The meaning of the first of these is apparent. The question of inventiveness is one which in its final analysis is properly determined by the patent attorney. The element of utility, however, is one of primary concern to the patent-conscious engineer.

In the chemical field, in general, and especially where the development is a composition of matter, the probability of allowance of claims and the ultimate scope and validity of claims is determined by the adequacy of the disclosure of utility. For a composition of matter to be patentable, it must be evident from the patent disclosure that such composition is useful. Such patent showing must, in general, be premised on the inclusion of one or more actual examples recording not only preparation of the composition, but also observed characteristics which make its utility obvious in a described use. Where it is desired to protect a class of compositions, it is necessary that the examples be sufficient in number to teach the utility of the entire class so claimed.

The general responsibility of all inventors with regard to the keeping of permanent, signed and dated notebook records of all of their daily work relating to inventions, is multiplied for the plastics engineer for whom oftentimes the stringent requirement of utility may necessitate a significant lapse between initial conception and the gathering of sufficient experimental data to form the basis for a complete patent specification.

There is no substitute for early filing, as many a late-filing applicant has learned to his detriment during proceedings between two applicants claiming the same invention. Therefore, the first responsibility of the inventor is to disclose his invention to his patent attorney with dispatch. However, where filing has been delayed as, for example, for the legitimate purpose of permitting adequate laboratory time to sufficiently demonstrate utility, an award of priority is oftentimes determined by the adequacy of pertinent records.

There are two record dates of paramount significance in the history of any invention. The first of these is the conception date. At the first inkling of an idea, and with each subsequent development, the engineer should make a complete signed and dated record of such facts, preferably in a permanent notebook. This entry, which is desirably made on the date of the occurrence of the recorded facts, should then be shown to another person who is capable of understanding the invention, and only after this other person has gained a complete understanding based either on an oral explanation by the inventor or upon the written disclosure, should he then subscribe the entry with a legend such as "Read (or explained to) and understood by me" which legend he should then date and sign.

The next, and considered by many to be the most important, date of concern is that of the first reduction to practice. The complete record of all acts and observed results should, of course, be entered, dated and signed by the inventor or by other persons performing the acts under the inventor's instructions. A reduction to practice in order to be of patent significance, although it need not demonstrate a development of the invention, to a commercially usable stage, must be sufficient to demonstrate utility, the latter gener-

(Please turn to Page 54)

SPEAKING OF EXTRUSION

Edited by R. D. Sackett
Technical Service Associate
Monsanto Chemical Company
Springfield, Massachusetts

Role of Barrel Pressure in Polyethylene Film Extrusion

Dr. Walter S. Kaghan
Development Section Chief
Film Division
Olin Mathieson Chemical Corp.

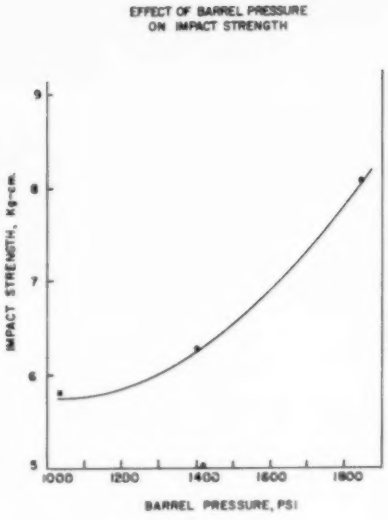


FIG. 1

A PANEL DISCUSSION. (1) on factors affecting quality in plastics extrusion was delivered before the Newark Section of S.P.E. in October, 1957. Much of the material presented in the formal discussion was drawn from a paper (2) presented by one of the panel members at the 13th Annual Technical Conference of S.P.E. in St. Louis in January, 1957. With the exception of one earlier paper (3) which discussed qualitatively the effects of extruder variables on properties of extruded polyethylene film, these are the first published discussions of extruder performance which attempt to include product quality in the evaluation of performance.

In attempting to improve productivity, film producers constantly strive to increase the output of their extruders. As Maddock so aptly states (2), however, true productivity for an extruder is its output of acceptable product and is, therefore, a combination of output and quality. Maddock defines quality in terms of the dimensional uniformity and macroscopic mechanical homogeneity. While these are undoubtedly important aspects of product quality, the film extruder has a number of more significant primary measures of film quality. This discussion is, therefore, concerned with the effect of one extrusion process variable, barrel pressure, on output and the more significant properties of polyethylene film.

In terms of its use as a packaging material, five readily measurable properties of polyethylene film are most significant today. These are slip and block, stiffness, clarity, impact strength and gauge uniformity. Other film properties which can be measured but are of less significance are tensile strength, elongation and tear strength. Ink receptivity or printability and heat sealability are other important film characteristics but these depend upon post-extrusion treatments.

While recognizing the interdependence of barrel pressure with other extruder variables, several generalizations can be made on the effect of increasing throughput rate and of barrel pressure on the film properties noted above. These comments apply only to films made from low density polyethylene resins using a slot die and a water quench system. The comments are summarized in Table I.

1. *Slip and Blocking Tendency*
   Increasing throughput rate will tend to improve both characteristics while increasing barrel pressure will tend to degrade them. The effect of anti-blocking and slip-improving additives in the resin, however, far outweighs the effect of processing conditions.
2. *Stiffness*
   Throughput rate and barrel pressure do not appear to have any measurable effect on this property.
3. *Clarity and Gloss*
   An increase in throughput rate will reduce clarity and gloss while increasing barrel pressure tends to restore them to levels obtained at lower rates.
4. *Toughness or Impact Strength*
   Film impact strength will be sharply lowered with significant increase in throughput rate. Higher barrel pressures will permit operation at comparatively high throughput

(please turn to page 44)

Table I

Effect of Increased Output and Higher Pressures on Film Properties

Property	Effect on Physical Property of Increasing Throughput Rate	Increasing Pressure
Slip-block tendency	increased	decreased
Stiffness	no effect	increased
Clarity-gloss	decreased	increased
Impact	decreased	increased
Gauge uniformity	decreased	increased
Tensile strength		
(machine direction)	increased	Tempers
(across machine dir.)	decreased	effect of
Elongation		increasing
(machine direction)	decreased	throughput
(across machine dir.)	increased	rate.
Tear strength	slight	slight

Edited by Louis Paggi, *Consultant, E. I. du Pont de Nemours & Co., Inc.*

Quality and the Automatic Injection Cycle

Milton A. Sanders
Vice President
Connecticut Plastics Products Co.

THE WORD AUTOMATIC, according to Webster, means self-moving. According to the molder, it means without human assistance; some take it to mean without quality. Such an interpretation is, of course, without basis in fact. We shall find, with a thorough study of all of the factors that establish quality, that through automatic molding the optimum of operating conditions can be obtained.

If we first analyze the injection molding cycle to determine its variables we arrive at the following elements:

1. Feed (volumetric or weight)
2. Injection pressure
3. Cylinder temperature
4. Pressure loss in cylinder
5. Nozzle temperature
6. Mold temperature
7. Mold open time

The element of feed contains a number of variables, depending largely on whether the feed is volumetric or weight. The weigh-feed system is more accurate as a general rule, thus it yields variables that are not of appreciable consequence in the overall variation pattern. The volumetric-feed system, however, because of its very nature yields the bulk-factor variable. In pelletized material the bulk factor is quite constant and only the effects of vibration in the machine tend to cause variations. With mixtures of regrind, feed variation can be as great as ten percent.

Injection pressure at the plunger is normally a closely held variable since most hydraulic systems are operated well above the critical pressure of the pressure control valve. The transmission of pressure through the charge of solid material is not so constant and produces a variable great enough to plague the molder when dimensions are critical. Since the volume rate of flow of material into the mold is approximately proportional to the third power of the pressure at the nozzle, a mold calling for 10,000 psi and having a pressure variation of 10% could have a filling rate variation of 30%. This would produce a variation in the injection dwell time as well as the cooling time in the mold.

Cylinder temperature is a cyclic variable, due primarily to the method of control used in the majority of cylinder systems. The straight on-off control permits relatively high-amplitude swings while the proportioning type provides a much lower variation. The stepless system is the closest to constant of all three systems; as a cyclic system, its frequency and amplitude of variation are low. The effect of cylinder temperature variation is more pronounced than that of pressure variation, primarily because a change in cylinder temperature produces a change in material temperature, material viscosity, pressure loss, flow rate, and cooling time. The impact of these variables is carried farther by the effect of temperature change on the mold temperature.

All of the variables above are independent of the machine operator, assuming, of course, that he is not permitted to change any operating conditions during normal production. The one element directly dependent upon the operator is mold open time. On very long cycles, this variable is not too effective in causing quality variation; on short cycles it may mean the difference between acceptable and reject parts.

Just what relation, then, does automatic molding have to quality? And, how valid is that relation when applied to both long and short cycles? To answer these questions we must consider the seven elements of variation and weigh each as it contributes to the quality of the molded part.

To the ultimate consumer quality is the measure of acceptance of a product. Dimensions, appearance, strength—these are characteristics of the product to which we must attach tolerances. It is the range of these tolerances which tells us how much variation our process may have and yet produce acceptable parts. Each element of the process contributes to the range of variations; no singular effect is without dependence on another. Thus, the variation in a given dimension will be more pronounced in a short cycle where the operator controls the mold open time than it will be in a long cycle where cycle control is automatic. Conversely, the dimensional variation may be no greater in a long cycle using an operator than in a short automatic cycle. It is the degree to which the variation occurs in each element that establishes the range of quality which ultimately results.

We describe automatic molding as a molding process in which all parts drop or are removed from the mold without assistance from an operator. Obviously we must design and build our mold to permit this form of operation. Nothing short of 100% performance can be permitted from the "automatic mold" or we would most certainly have repeated interruptions in the cycle. Can we assume then that, if the automatic mold is designed to eject all parts completely from the mold, the semi-automatic mold is not so designed? Evidently no mold is deliberately designed to have parts stick except in those cases where dropping would cause damage. It is apparent that the automatic mold therefore receives more rigorous attention both in design and construction. Once constructed and installed in the injection machine, the mold receives more intimate supervision at the start of its production run since to perform automatically it must have all adjustments at essentially the optimum settings.

The semi-automatic mold, if it can be so described, can be assumed to be short of 100% performance because the operator is available to remove parts which do not eject satisfactorily. (This naturally would not be the conclusion for those molds in which deliberate holding in the mold is necessary to avoid the damage caused by dropping). Thus, if in a multiple cavity mold, all cavities are made identical with each other, the sticking of one part would tend to indicate that that specific part is different from the others and thus might possibly be out of tolerance. The tendency on the part of the molder is to tolerate the sticking

because the operator is there to remove the part; correcting the mold or devoting more time to the setting of conditions would consume more initial cost. Thus, the molder must decide, in semi-automatic production, whether the malfunction of the process can be economically corrected or whether he may risk the possibility of reduced quality by permitting the malfunction to continue. An additional alternate is available in semi-automatic production: the operator may be instructed to alter operating conditions from time to time to overcome the apparent malfunction of the process.

Comparing the automatic with the semi-automatic process we find one significant difference: the range of variation permissible for continuous performance of the automatic process is narrower than that for the semi-automatic. Thus, the seven elements of the process are controlled so that their net effective variation is a minimum for the automatic cycle.

In studying any process where a series of variables is known to exist, it is necessary that only one variable be adjusted at a time in order to permit valid conclusions to be drawn. This is fundamental to all experimental techniques. Thus, in injection molding, the adjustment, for instance, of mold temperature will yield a set of results that may be intelligently interpreted if all other factors remain constant. Automatic molding affords the best possible means of studying the effects of variation since not only are all elements maintained at the same control position for each cycle but their cyclic interdependence is maintained. The elimination of the human element from the process removes the random variable and thus eliminates the biggest unknown.

To study the effect which the various elements have on the quality level of a molded part, let us take a hypothetical cycle and attach to each part of the cycle the pattern of quality change that takes place with the variation of that part of the cycle. For simplicity, let us assume that the part is a styrene closure in an 8-cavity automatic unscrewing mold; the press will be assumed as a 4-oz. of latest design with stroke interruption to permit unscrewing and ejection. The cycle could conceivably be the following:

A. Press close	2 secs.	x
B. Injection forward		
1. Fill time	2 secs.	x
2. Dwell time	3 secs.	x
C. Injection return		
1. Return time	2 secs.	
2. Prepack	3 secs.	
D. Cooling time	5 secs.	x
E. Press open		
1. First stage	1 sec.	x
2. Unscrew	3 secs.	x
3. Second time	1 sec.	x
4. Reset	1 sec.	x

Those parts of the cycle which are additive are indicated by "x". The total cycle is seen to be 18 seconds. Certain specific features of this cycle may be noted. First, the total time for the mold faces to be exposed to room temperature is 8 seconds. Second, the total time each charge of material is exposed to heating per molding cycle is 18 seconds; i.e., for instance, 20 cycles are required for the charge to pass completely through the cylinder, heating would take place for 360 seconds. Third, of the total cycle, only 10 seconds are actually effective for cooling the parts with the mold closed. Fourth, the cooling time under full mold conditions is 8 seconds.

Analyzing the cycle components it is readily seen that with 360 seconds or 6 minutes for heating the material a small variation in cylinder temperature would not produce an appreciable effect on the net temperature of the material as it arrives at the cavity. In the opposite direction controlwise, with a full time of only two seconds, any delay in the shift of the valve spool for the injection hydraulic cylinder would greatly affect all quality attributes. This is particularly true in dual pressure injection systems. Cooling time for both parts and mold faces fall in the medium range of sensitivity but variations of more than a few seconds would show up as dimensional effects. Longer cooling time would make unscrewing more difficult and might possibly slow down the unscrewing device, further extending the cycle time. Shorter cooling time might possibly create distortion during unscrewing.

Of the total cycle of 18 seconds only 8 seconds are consumed with complete parts in the mold. These 8 seconds have a direct effect on the quality of the part. The remaining 10 seconds have an effect principly on the temperature factors of both material and mold. The injection machine controls the 8 seconds of true molding time with sharp regularity. The 6 seconds of press open time, if manually controlled, could conceivably vary by more than 2 seconds, producing the random variable that upsets the equilibrium of the cycle.

Experience over a number of years with the operation of automatic injection presses has clearly shown the benefits obtained with respect to quality. The savings in direct labor can be applied toward increasing the quality of the mold and toward closer attention to control of the cycle. The elimination of rejects through the elimination of random variables is the ultimate result of automatic operation. It is this result which we all seek since in the final analysis quality is the yardstick by which we measure our competitive success. ★ ★

SPEaking . . .

(Continued from Page 42)

rates while maintaining an acceptable level of film impact strength (Figure 1).

5. *Gauge Uniformity*

   Increased barrel pressure seems to improve control of gauge uniformity which is adversely affected by increasing throughput rate.

6. *Tensile Strength and Elongation*

   Increasing extrusion rate results in greater machine direction orientation. Consequently, machine direction tensile strength increases while machine direction elongation decreases. The transverse direction properties behave in the opposite manner. Higher barrel pressures temper these effects.

7. *Tear Strength*

   Throughput rate and barrel pressure have only slight effects on this property.

It can, therefore, be seen that increased output of acceptable film from an extruder can not be achieved by merely increasing the screw speed and pushing resin through the extruder at a higher rate. If the operation is carried out at higher barrel pressures, however, higher output of good quality film may be obtained.

Obviously, an increase in barrel or back pressure, of itself, will cause a decrease in extruder output, all other things being equal. It is also apparent that other extrusion process variables such as melt temperature, screw speed, die opening, etc., have significant effects on barrel pressure. Fortunately, the barrel pressure may be varied independently by means of restrictions (valves) in the die or at the extruder outlet. Increasing the density of the breaker plate screen pack or inserting valves between extruder and die have been recommended (1, 2, 4). ★ ★

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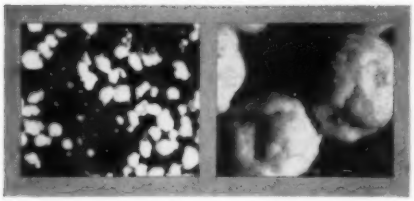

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CYANAMID

PLASTICS NEWSFRONT

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Solves pH Meter Housing Problem

Housings for Pocket Model and Zer-o-Matic* Bench Model pH meters must be tough, strong, impervious to chemicals and corrosion-resistant. Beckman Instruments, Inc., chose CYMEL® 1077 melamine molding compound. This tough, break-resistant plastic protects the delicate mechanism, provides color that cannot wear or chip off and eliminates use of metal subject to corrosive attack.

**Trademark Beckman Instruments, Inc.*

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Action— By Your National Organization

"The objects of the Society shall be to promote in all lawful ways the Arts, Sciences, and Engineering Practices and Standards connected with the utilization of plastics."

NATIONAL COUNCIL ACTION
April 15, 1958

Financial

Your National Council at its most recent meeting held on April 15 in Washington, D.C., passed a record budget for the fiscal year 1958 to 1959. This budget, directly reflecting the increased size and activity of the Society, is in the amount of $293,218.75.

National Finance Committee Chairman Jules W. Lindau III presented a third quarter financial report that adequately attested to the healthy financial condition of your Society.

Membership

Our National Membership Committee, under the able Chairmanship of Frank W. Reynolds, has launched upon a membership program which should prove to be the most successful program ever. In its attempt to achieve our President's goal of 1,400 new members by January, 1959, the Committee's plan is not only to operate on a National level, but also to work diligently with local Section Membership Committees, in close co-ordination with the Area Chairmen.

A first major step in this direction has been the publication of our new membership brochure that had just come off the press when presented to Council. Your National Officers feel confident that the entire membership will get behind this Committee's program, and thereby assure the Society of the greatest increase in membership ever achieved in one year.

Publications

Administrator and Acting Chairman, National Publications Committee, Christ Kacalieff, presented for approval, a new Manual of Procedures, SPE Journal, which Council approved as a tentative procedures manual. This very excellent work is designed to assure the Society of good, efficient, and uniform procedures in the many detailed tasks of editing and publishing our SPE Journal.

Technical

Administrator of Technical Committees Fred C. Sutro, Jr. reported that our latest Technical volume "Principles of Thermoplastics Processing" will be ready to go to press very shortly, thus assuring publication of the volume this year.

The Committee also reported progress on the volume "Injection Molding". The Committee plans to commence work immediately on the proposed volume "Principles of Thermosetting Processing."

Meetings

The following RETECS were approved by Council:

Buffalo Section RETEC on "Plastics Finishing", October 18, 1959 at Niagara Falls, N.Y., with cooperation of the Plastics Finishing P.A.G. Group.

Philadelphia Section RETEC on "Advances in Injection Molding", November 6, 1958, at Philadelphia.

Constitution

Constitution and By-Law Committee Chairman, Wayne I. Pribble, reported excellent progress on the complete rewrite of our Constitution, By-Laws, and Rules. The Committee plans to have the first complete rewrite draft ready for June mailing to all Councilmen for suggestions and criticisms. The final draft will then be prepared for presentation to Constitution meeting of Council in September. The Committee then hopes to have the revised Constitution, By-Laws and Rules submitted for discussion and amendment at the annual business session during our January ANTEC in New York City, following which it will be submitted to the entire membership for letter ballot.

As you probably all know, these sections are the culmination of over three years hard work by your Constitution Committee. It is hoped that this Committee will be given well deserved cooperation in their quest of suggestions and criticisms, so that these final stages of rewrite and acceptance can be accomplished, and that our long-awaited, streamlined, efficient, and up-to-date Constitution will become a reality.

Presidential Appointments

President Gossett presented his appointees to all National Committee Chairmanships to Council for their approval. Council gave our President a unanimous approval.

This complete list as approved, will be published in our June roster issue of the Journal.

Next Council Meeting

National President Gossett has announced that the third regular meeting of the 1958 National Council will be held on June 20, 1958, in Indianapolis, Indiana.

In summary, your National Officers would like to take this opportunity to thank each and every National Committee Chairman, Committee member, Local Section Officer, and Local Section Committeeman, that have extended such wonderful co-operation and effort to this administration. We have every reason to believe that through continuance of this fine co-operation, we will together make this a banner year for the Society of Plastics Engineers.

Sincerely,

George W. Martin

National Secretary

Binghamton

Tooling Cavities for Spur and Helical Gears

Leo J. Pranitis

The Binghamton Section met at the Vestal Steak House on March 27, 1958. Our president, Emery Slaght, opened the meeting by introducing the eight new guests to the 29 members present this evening.

The reading of the minutes was followed by a treasurer's report and an announcement by Mr. Slaght that the plans for our 2nd Annual Dinner Dance coming up on May 17th were beginning to solidify and the entire project was rolling along wonderfully.

Len Wheeler of American Plastics introduced our speaker for the evening—Joseph R. Venne from International Business Machines Corp. in Endicott, New York. Mr. Venne is a member of the Binghamton Section and his topic was "Tooling Cavities for Quality Class Commercial II Spur and Helical Plastic Molded Gears".

This presentation dealt with the method developed by the IBM Endicott Plastics Laboratory to make the gear cavity pattern used to produce the mold for Commercial II Plastic molded gears. This method has been used successfully to mold gears from 1½ inches in diameter up to 4½ inches in diameter.

Mr. Venne's talk was supplemented by slides illustrating typical gear cavity patterns, mold cavities formed by gear patterns, and close tolerance gears molded from mold cavities.

Our next meeting will be held at Vestal Steak House on April 24th and our speaker for that evening will be Russ Houghton who will speak on "Plastic Research, Fact or Fancy, From a Manager's Point of View".

Toledo

Custom Molding Management Problems and Plastic Pipe

R. E. Dunham

On February 26, 1958, the February meeting of the Toledo Section was held at the Old Plantation Inn.

The meeting opened with the introduction of the new President, by our National Director, Don Bowlin. He introduced the other new officers: Herbert Pioch—President; James Hylands—Vice-President; Peter Swartzbaugh—Secretary; and Ronald Wagner—Treasurer.

Don Bowlin gave a detailed report on the happenings at the National Meeting in Detroit.

Andrew Kassay introduced the speaker, Mr. Robert L. Davidson, Vice-President, Sales of Kurz-Kasch Inc. and Vice-Chairman of Molders Management Division of S.P.I., whose subject was "Management Problems of a Custom Molder".

Mr. Davidson expressed concern over the lack of basic research being done by molders because of a lack of funds, even though there are over 1500 molders.

He feels the future of custom molding job shops lies in one of several possible directions. A survey concluded that a point is reached in size where they must double their size or discontinue operations because of dropping profits and rising costs. There has been suggested, as a remedy, the possibility of a central office in control of several small plants close to customers.

The big business theory can be tried by putting in large amounts of money and building a complete plant at one time.

At present, the large molders seem to be losing ground and small molders are predominating in the custom molding field.

Mr. Davidson feels that the future will bring the development of an organization of specialists companies, under one management. In order to grow and prosper, the small custom molder of today is almost forced to develop proprietary items while acting as a custom molder job shop and then to discontinue custom molding.

Following an excellent dinner, the March meeting of the Toledo Section was called to order by the President, Herb Pioch. The meeting was held at Harrison's Ranch House on March 19. After a short business meeting, Andrew Kassay presented the speaker, Mr. H. W. Kuhlmann of Battelle Memorial Institute of Columbus, Ohio.

Mr. Kuhlmann presented a large number of graphs, charts, and slides and discussed in detail, the procedures followed in developing test methods to set-up standards for plastic pipe and reinforced materials.

St. Louis

Optical Design of Lucite

R. A. Karasek

The March meeting of the St. Louis Chapter of the Society of Plastics Engineers was held at the Prime Rib Restaurant, March 18, 1958.

The meeting was called to order by Robert McDorman. There was a report given by Christ Kacalieff concerning the national committee and the scheduling of one-day RETEC in various sections. We also had a talk from Dick Baumgartner, our treasurer, in which he gave a report on the financial status of the group and the bar kitty.

The speaker of the evening was Mr. James H. Crate, Sales Technologist for E. I. DuPont de Nemours Company. The subject of his talk was the "Optical Design of Lucite." Mr. Crate pointed out how a part must be designed keeping in mind the refractory index of the material involved. Light beams or rays of light can be directed in the proper way through proper design. To get satisfactory lighting or reflection, you must trace the pattern of light beams so that they are directed to the proper point.

Newark

Recent Developments in Injection Molding and Extrusion

Fred W. Ducca

The March dinner meeting was well attended at the Military Park Hotel. Two speakers from the Technical Service Department of the Monsanto Chemical Company discussed the newer advances that had been made in fabrication by injection molding and extrusion.

With regard to injection molding, Ralph E. Hammer considered both materials and equipment. New materials that he mentioned together with their uses are as follows:

Polystyrene—45% is rubber modified and the static dissipating type is growing in usage.

Acrylics—Being used for shoe heels.

Polycarbonates—Have a 12.0 impact and heat distortion of 280°—290°F.

Delrin—an acetal resin.

Teflon-100X—new melt extrudable fluoro-carbon resin.

Polypropylene—housewares.

Recent types of equipment that have come into use are preplasticizers, conical heat chambers, hot runner molds, multiple gating, high-speed injection and telescopic mold closure.

Mr. R. D. Sackett was the next speaker who mentioned some of the current ideas in the field of extrusion. He pointed out that plans are under way in the SPE to increase the knowledge of the theory of extrusion and to seek agreement in the trade on extrusion terminology. As far as the extrusion technique is concerned, there is a growing trend toward vented extrusion and induction heating. Induction heating is the method in which heat is generated by the lines of magnetic force developed in the walls of the barrel by a coil wrapped around the barrel using 60 cycle, line voltage. Another trend is toward high speed extrusion which may surpass induction heating. Interest in both topics presented by the speakers was evidenced by a prolonged question period.

Allan Serle of Shaw Insulator Company, Chairman of the Education Committee, reported that the spring semester starting in April at Newark College of Engineering would include two courses in plastics. They are Injection Molding and Thermosetting Process Techniques. The Newark section has been sponsoring courses in plastics which have attracted considerable attention as shown by the large attendance.

An all day outing is planned for the Newark section at Forsgate Farms in Jamesburg. The chairman, Bill Bradbury of Injection Molders Supply, promises a bang-up all day affair with golf, baseball, soft ball etc. He promises to tailor all sports in accordance with each member's capabilities. He further pointed out that Forsgate Farms is the largest privately owned dairy in the country. (Is this offered as an inducement to those on the wagon, Bill?) Outing date, June 11.

R.I.S.E.M.

Start Memorial to William Dunnican

Glenn A. Tanner

The March meeting of the R.I.S.-E.M. Section was held March 27th at Topp's Gaylord Restaurant in Providence, Rhode Island. Eighty-five members were present to mingle in fellowship, partake in steak, and to listen to Mr. R. T. O'Connor, Research Director of Devcon Corporation give an excellent talk on plastic molds. Our President, Charles Chrones of Hassenfeld Brothers, announced once again the annual Ladies Night, which will be held on May 22nd at the Pawtucket Country Club. This is annually a gala event and once again this year we are expecting a big attendance. Director, Howard Bangs of Plastimold Corporation reported the progress he has made to date in the arrangements for the memorial to William Dunnican. Mr. Dunnican not only was instrumental in starting our section of S.P.E., but he also played a leading role in the beginnings of the Connecticut Section and the Eastern New England Section. These Sections will be contacted to see if they are interested in joining in this memorial. Mr. Bangs already has received an expression of cooperation from one of Mr. Dunnican's former employers.

Following the business meeting, Mr. R. T. O'Connor presented an illustrated talk on "Use of Devcon C for making low cost Molds". Since Mr. O'Connor is Research Director of Devcon Corporation, he can speak on this subject with authority.

He pointed out that it is the chemical structure of the Epoxy resins which is responsible for their physical properties and it is, therefore, the problem of the plastic chemist to develop ways of controlling these chemical structures so that the material will contain the desired physical properties. For mold use, the properties required are: (1) Easy to use, (2) Ability to machine easily, (3) Ability to withstand 400°F, (4) Low shrinkage, and (5) High strength at elevated temperatures. After much work, the people at Devcon feel that they now have obtained a majority of these properties by using special hardening agents, metal filler, and high temperature epoxies. Their material, after molding, is cured for five hours at 250°F and ten hours at 350°F.

Since preparation of the model is extremely important in the success of making a plastic mold, instructions for preparation of the model are sold with all Devcon materials. Our speaker pointed out that the model can be of metal, wood, plaster, or even plastic. Different techniques are required for repairing each of these different materials before casting the mold.

Since the plastic cavity must be supported with metal, Mr. O'Connor showed several means of accomplishing this. He also showed methods of placing copper coils in the molds prior to casting for cooling purposes. Since the epoxy resins do not have the conductivity of metal, more cooling is required than would normally be built into a steel mold.

The cost of producing the mold, even with these added cooling coils, is, of course, far cheaper than a conventional mold. He cited instances where a mold costing $3,000 was reproduced in plastic for $380.

In response to questions regarding the durability of such molds, Mr. O'Connor replied that this, of course, would vary with the part, material used, and the type of molding. However, as a method of comparison, he stated the molds were generally good for 10,000 injection molded parts, whereas in compression molding the molds would only suffice for 100-500 parts.

In answer to further questions, Mr. O'Connor stated that, in compression molding, although the molds do have an application for sample production, they require about twice as long to cure the parts, due to poor heat conductivity of the material. He also stated that, because of the different coefficient of expansion, it is not possible to imbed steel into the cast material to assist in strengthening the mold. Doing so would result in cracking the mold.

For door prizes, Plastimold Corporation donated a starter set of melamine dishware and the A. J. Krajewski Company donated a picnic hamper and a beach bag. The prizes were won by Mr. Arthur Travis, Mr. Stanley Dreczka, and Mr. Dean Bascom.

Southern California

Tooling for Injection Molding

John A. Stahmann

A new meeting place, the Eleda Restaurant, was the locale of Southern California's March technical session. Primary consideration was given to injection molding of polyethylene and cellulosics.

The evenings speaker was Mr. Melce C. Taylor, who has been associated with Eastman Chemical Products for the last 22 years. He presently is their technical representative for the Los Angeles area.

Mr. Taylor pointed out that in the old style injection molding machines no drying or proportioning devices were used. The modern machines have weigh feeders, loaders, driers, additional nozzle and tool heaters, and blocks and coring of improved design. Hot runner molds are not the answer for cellulosics or polyethylene, however, since distortion, poor finish, and heat marks will be caused.

Post-meeting examination of Samples. Left to Right—John Stahmann, Leo Costanza, Melce Taylor, speaker; Jack Fuller and Tom Schaub.

Photograph courtesy of Western Plastics

A removable tip nozzle with exterior threading was suggested for ease of flushing when it is necessary to change materials. Full round runners centered on the parting line of the mold were suggested for good insulation and material flow. A trapezoidal cut in one face is cheaper to machine and gives about the same effect. Half round runners tend to freeze up. Restricted gates should be used; if the gate is machined straight there is a tendency toward straining. Deeper and larger gates should be used for trapezoidal runners. Multiple gates do a better job than a single gated mold.

Mr. Taylor continued his talk with illustrative slides which explained the proper positioning of tabs, cutoffs, restricted gates, heavy section work, and offsets. Sheeting, coating, and wire coating dies were discussed. These were aptly shown by drawings of the pertinent section. Mr. Taylor concluded with demonstrative samples.

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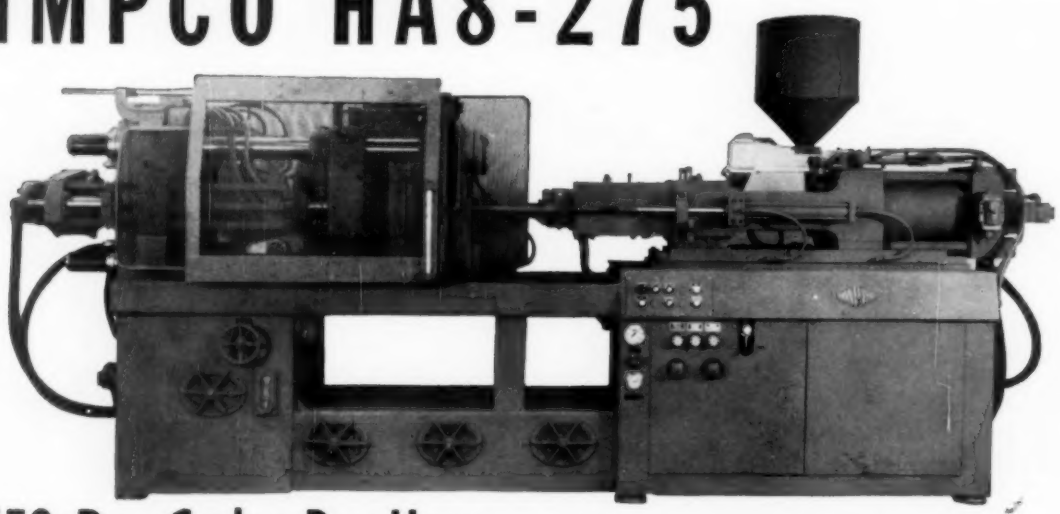

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AROUND THE WORLD

★

UNITED STATES

A.S.T.M. BULLETIN

January, 1958

Abstracter: Walter A. Gammel, Sr.

Brittleness Temperature Testing of Elastomers and Plastics—*A. C. Webber*

Round robbin tests on gum rubber, polyethylene, plasticized vinyl, SBR compound, and neoprene indicated that of all published test methods on subject only ASTM D-746-55 was useful over range of materials tested.

"A material is brittle if when stressed to fracture, it breaks with little strain, low energy absorption, and with a relatively smooth or conchoidal fracture surface or evidence of crack propagation." Two of the principal variables in studying brittleness (which is **not** a fundamental property of the material) are temperature and the rate of development of strain.

The task group concluded also (1) that results from solenoid and motor operated equipment produced no significantly different results (2) found good correlation between calculated and graphical results and (3) failure criterion of "any visible failure" was much preferred to the formerly specified "complete separation."

Significant factors in brittleness testing are method, instrument, specimen, conditioning time, application of force, rate, number tested, and report. The article cites most pertinent references.

The effect of loading rate on Adhesive Strength—*Frank Moser and Sandra Knoell*

For a crosshead movement machine ASTM specifies jaw separation rate of 0.05 in/min and for a hydraulic machine a loading rate at 600 lb/min. when evaluating adhesive bonds. The authors tested three adhesives using both types of machines. Loading rates were standard and twice standard.

It was found that with high-elastic modulus adhesive a significantly greater strength was noted at the higher loading rates than for low-modulus adhesives. At the lower loading rates plotted data had a curve indicating a guadratic effect. At double loading rate a linear relationship was approached.

★

MATERIALS IN DESIGN ENGINEERING

February, 1958

Abstracter: Leonard Buchoff

Effect of Temperature on Industrial Laminates—*Norman A. Skow*

The electrical and mechanical properties of nine laminates are presented over a temperature range of -90°F to 200°F in a series of curves. Flexural and impact strengths of the laminates are better than was expected at the temperature extremes. Grade G-7 silicone glass laminate, shows extremely low, consistant power factor and high insulation resistance at all temperatures tested. Curves show that G-10, glass-epoxy, is superior to G-3, glass-phenolic, and XXXP, paper phenolic laminate, in insulation resistance under moist conditions above 30°F.

★

GERMANY

KUNSTSTOFFE

December, 1957

Abstracter: Leo Fischer

Inner and Outer Protection of Pipe Lines and Apparatus with Heat and Flame Spraying—*F. Ritter von Ruling*

In all cases, even when a solvent technique is used in coating pipe lines and apparatus, it is desirable to warm the liquid. The solution can be in paste form and the viscosity reduced by heat. Not only speedier drying but a heavier coating per second of spraying is thus obtained. Not only should the liquid be preheated but the tubing to the spray gun and the spray gun itself should be insulated. One problem with such technique is the susceptibility to moisture absorption of a hot mix.

The author describes a new type of flame spray gun which he invented. Only fuel gas and compressed air is used. The unique feature of this gun is a double mantle funnel nozzle at the spraying head. The flame is actually protected from the adverse action of the compressed air that ejects the liquid; at the same time, infinite variation in heat control is possible. Another advantage is that the flame of the gun can heat the spray surface during spraying. Practically all moisture contamination is eliminated. Since the sprayed film is subjected to a quick post melting action, a very superior film is formed. Even water emulsions can thus be successfully sprayed.

Analysis and Testing of Synthetics in Periodical Literature of 1956—*Dr. K. D. Ledwoch and H. Meisel*

This very useful article summarizes the world literature related to testing of plastics. The groups of tests covered are chemical, physical, spectroscopic and electrical. The groups of plastics are natural high polymers, such as cellulose, lignin, silks, wool, etc.; raw materials and auxiliary products; fabricated products; new testing apparatus; test specifications.

Polyurethane Foams in the USA — *K. H. Kranse*

This article is a comprehensive discussion of polyurethane foam production methods in the USA. It is estimated that American production will rise from 30 million lbs in 1957 to 50 million lbs. in 1958. The chemistry of polyurethanes is explained, excellent charts are included and the various application techniques are described. A good bibliography is included.

★

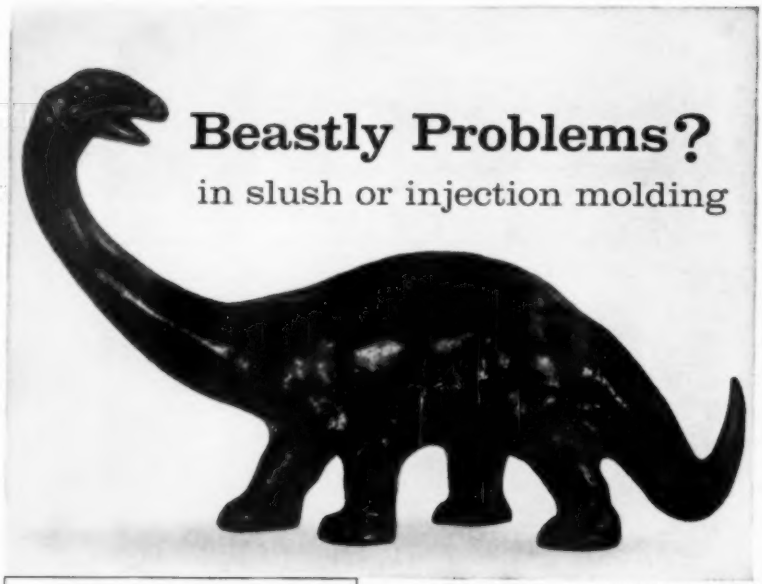
DER PLASTVERARBEITER

December, 1957

Abstracter: Leo Fischer

Organization in the German Plastic Industry

The officers, their addresses and affiliations as well as the leading subdivisions and the committee chairmen of the leading German plastics organization are given.



Slush molded toy by J. H. Miller Company

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SLUSH MOLDING

Polyethylene for slush molding is brand new! Now, using a blend containing low-viscosity A-C Polyethylene, parts can be fabricated from small pieces like the toy dinosaur above to 50 ounce parts. Here's an entirely new low pressure process offering faster cycles with low mold and machine costs. Because molds are inexpensive, short runs are economical for polyethylene parts using this entirely new material. Adaptable to individual piece, semi-automatic and automatic operations, slush molding with polyethylene provides new control of molding costs with detailed, high quality finished parts. Only A-C Polyethylene blends give maximum results for a wide range of working conditions.

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New Textiles with Metallic Threads — *H. Heiner*

New non-tarnishing threads made from Mylar polyester metal film are described. The vacuum coated film is on the inside of the laminate and thus has a high, permanent gloss. The film is extremely fine and thin strips almost like threads are interwoven with textiles for clothing, furniture covers, even lingerie.

How is Premix Worked — *Hugo Brendel*

In a description of premix technique, it is especially noted that too high pressure is injurious to premix molding. The author describes a continuous operation where the roving is cut and the mix is made and fed to the press as a preform.

Technique of Extrusion — *Jean Peynichon*

This is the seventh installment of a detailed article on extrusion. This article deals with types of extrusion equipment. Double and multi screw extruders are discussed and the different feeding devices are explained and illustrated.

Development of Petro Chemical Industry—*Dr. W. Erdmann*

The author explains the superiority of petroleum over coal in the chemical industry by the fact that coal contains only 4-5% hydrogen and petroleum 13-15%. The general divisions of oil extracts are given, such as ethylene, propylene, and butyl. The petro chemical industry of Western Europe uses 600,000 tons of oil annually and expects to absorb a million tons in 1959. By 1965 it is expected that the petro chemical industry in the USA will represent 55% of total American chemical industry. Synthetic rubber absorbs a good deal of this.

Butyl—A Synthetic Rubber—*Dr. Wm. Sparks (Esso)*

Dr. Sparks, in a lecture in Frankfort, gives a technical history of the development of synthetic rubber, starting with the search to understand natural rubber. The chemical structure of polyisobutylene and natural rubber is compared. He then discusses the nature of vulcanization. Unsaturation and the quantity of double bonds in the chain are necessary for vulcanization. Complete saturation prevents vulcanization. The realization was an important step in understanding elastomers. It was then found that saturation by substitution with phenol groups, aromatics, halogens, etc., could also produce results equivalent to vulcanization. He also discusses the nature of carbon black in rubber and synthetic rubber. An analysis of applications of rubber is given and a comparison between natural and synthetic rubber is made.

★

FRANCE

INDUSTRIE DES PLASTIQUES MODERNES

January, 1958

Abstracter: Hans Mayer

Injection Molding or Vacuum Forming — *Jacques Combette*

The question of method in the production of a manufactured product is determined by the product specifications, the amount of parts required and the machinery and raw or semi raw materials available for the job. The manufacture of good sized products from thermo-plastic materials puts the question of preference of method between injection molding and vacuum forming. Besides describing the different methods and difference in the raw materials required, the article investigates the comparable methods of tooling, production rates, finishing costs, etc. The limitations of either one of the methods are also explored.

The Influence of Temperature on Reinforced Polyester Moldings. Rhodesters Tested.

An investigation into the question whether elevated molding temperatures are harmful or preferable to low temperatures in the molding of reinforced polyesters, covers the subject of temperature influence on the vicosity of the resin, the temperature influence on pressure moldings, on the duration of the gel time and concludes that the elevated temperature was of no harm in the case of the resins (Rhodester) used for the test.

Plastics Can Transform Agriculture— *Jules Soyeur*

In this third installment the author enumerates the various methods which have been developed for the economic application of polyethylene films in the raising of vegetable and fruit crops.

★

L'OFFICIEL DES MATIE'RES PLASTIQUES

January, 1958

Abstracter: Alexander Baczewski

A New Technique for the Manufacture of Non-supported Film

This process makes it possible to manufacture economically on a new machine sheeting of more than 6 feet width and from ⅛ to ⅜ inches thickness. Most thermoplastic materials lend themselves to this technique and the resulting sheeting is absolutely free of stress.

A cylindrical block of the plastic material weighing about 1000 lbs is extruded and fastened at both ends. The block rotates slowly and the film is cut off it just like veneer is shaved off a log in the manufacture of plywood.

The resulting sheeting can be used for the waterproofing of buildings and tunnels, for chemical apparatus and as a continuous heavy duty floor-covering.

Competitive methods are described and criticised, the economics of "rotary cutting" are explained and the French patents for this new process are given.

Cultivation of Castor Beans in France

For the first time castor oil plants have been grown successfully in France. Yields of oil are not given.

A New Machine for the Manufacture and Reproduction of Molds

SCRIPTA, Paris, manufactures a new version of the old pantograph which produces and reproduces molds. One arm scans the sample and the other arm shapes the mold.

Plastic Materials Combat Corrosion — *V. Decans*

Techniques of shaping and applying various plastic materials for the process industries are discussed in detail. Four specific examples are given (manufacture of HCL, the pickling of steel, a winery, storage of petroleum products)

A New French Industry, Plates for Press Polishing

Chrome plates for press polishing have been imported until 1957. They are manufactured now by a French company. The manufacture is described in detail. (illustrations)

Machine for Vacuum Forming

A machine (Formvac U-5) manufactured by Hydro Chimie Zurich Switzerland is described. It is fully automatic and is capable of shaping articles up to 36x54 inches large to a depth of 20 inches. The machine is easily transported and assembled.

February, 1958

Plastic Materials Combat Corrosion — *V. Decans*

This fourth installment of a series on how to apply plastics for the process industries shows how to join plastic sheeting and gives some information on spray techniques, including flame spraying.

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Plastic Materials in Wineries — *H. Neychen*

Recently the wine industry of France has begun to utilize the chemical inertness of PVC for pipes and various apparatus. Unplasticized sheet and PVC pipes are usually combined on location with the aid of specialized heat guns using a technique similar to the soldering and welding of metals. Plastic welding rods are used. A most fascinating discourse on the use of polyethylene for champagne stoppers follows. The underlying research began only after the safe use of polyethylene for baby nipples had been established.

★

CANADA

CANADIAN PLASTICS

January, 1958

Abstracter: Samuel S. Oleesky

Irradiation Improves Polyethylene Coated Cables — *Leo Walter*

A thorough paper on properties and methods of test for wires and cables coated with irradiated polyethylene. The article is implemented with tables and curves showing detailed procedures and test results. The author gives an explanation of the reasons for his conclusions in a manner that is readily understood. Good reference material.

Deep Draw Forming at High Production

Excellent detailed discussion and step-by-step procedure of a new technique in vacuum forming, which enables the processor to form deep-drawn parts from heavy gauge polyethylene with good thickness uniformity and relatively low corner radii. The method is said to be equally successful for thin or heavy gauge Kralastic, styrene, vinyl, and other thermoplastics.

Printing on Films — *Peter Absalom*

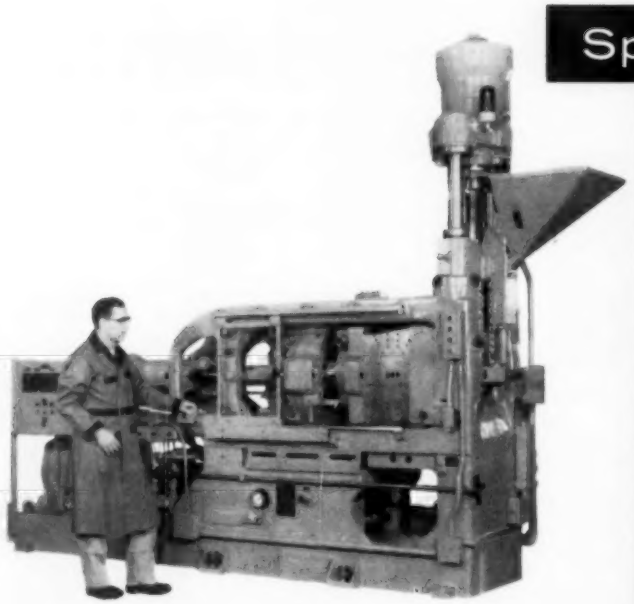
Comprehensive article on the art of applying inks to plastic films. Includes a description of the types of machinery needed, the various ink applications, including multi-color printing, treatment and handling of the films, and some of the problems of operation, such as elimination of static electricity.

Patent Law . . .

(Continued from page 41)

ally by actual test results, so that, for example, development of a new dielectric material necessitates the measured dielectric properties of such materials.

The element of corroboration in proving a reduction to practice date is very important. For a reduction to practice date to be of any legal significance, it is necessary that it have been witnessed in its entirety by a person or persons other than the inventor or a co-inventor, either collectively or in succession, who can of their own knowledge testify to the chemical nature of all involved materials, and also as to all steps performed and all results observed. Such requirement of corroboration is most easily met by having a person skilled in the art, other than the inventor, perform all acts required under the direction of the inventor. Such witness should, of course, have a complete understanding of the invention and should keep his own written record. ★★



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Pressure on Material at End of Plunger, P.S.I.	20,000
Speed of Injection Plunger, inches/min.	171
Filling Speed, cu. in./sec.	12
Complete Machine Cycle, idling, secs.	9
Mold Opens, inches	10
Maximum Mold Height, ins.	16
Minimum Mold Height, ins.	13
Maximum Mold Size, ins. (H x V)	28 x 23
Total Heating Units, K.W.	11.1
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Weight, Lbs.	19,000

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book reviews

POLYAMIDES

Donald E. Floyd, General Mills, Inc., Minneapolis, Minn. Published by Reinhold Press 230 pp. $4.50.

During these times when everything is in a rush, it is a pleasant task to obtain a book that has eliminated much non-pertinent data, and presented the subject matter clearly and concisely. The subject matter of polyamides is balanced well between the nylons and the Versamids. The author could have easily succumbed to a natural prejudice in treating the latter compounds excessively.

It is believed that the book is a little beyond the appreciation of the stated Publisher's intent of appealing to "design engineers, equipment manufacturers, etc". It is an excellent book for the chemist and materials engineer as well as the technical student.

In reading the book, it is suggested that the third chapter on Basic Chemistry of the Polyamides be read first in order to appreciate more fully reactions and compounds listed in the first and second chapters. Unless the reader is an excellent and active student of nomenclature the information presented in the first and second chapters may easily be confused.

This is the third volume in a series of 14 volumes that the Publisher is planning on Plastics. If the subsequent volumes measure up to this book, the series should be an excellent one.

Edward B. Murphy
Massachusetts Institute of Technology

X-RAY CRYSTAL STRUCTURE

Dan McLachlan, Jr. New York: McGraw-Hill Book Company, Inc., 1957. xiii + 416 pp. $15.00.

This book deals with the field of research concerned with the determination of crystal structures by X-ray diffraction analysis of single crystals. It is one of relatively few books (apparently the first published in this country) that cover the elementary theory and techniques involved in substantially all of the essential steps in determining a crystal structure, from taking the first X-ray diffraction photographs for unit-cell and space-group determination to the performing of the computations required for determining the positions of all of the atoms.

While the essential steps are well covered, many associated topics often important in structure determination are treated very briefly or not at all: such topics are optical properties, piezo-and pyro-electricity, absorption and extinction, mosaic structure and imperfections, anomalous dispersion, and (importantly) procedures for refinement of atomic coordinates and for estimating their precision. Powder and fiber methods, and studies of macromolecular substances, are not treated. Also essen-

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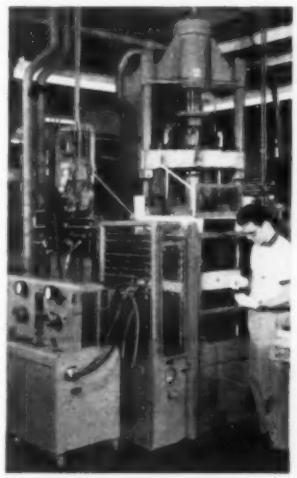

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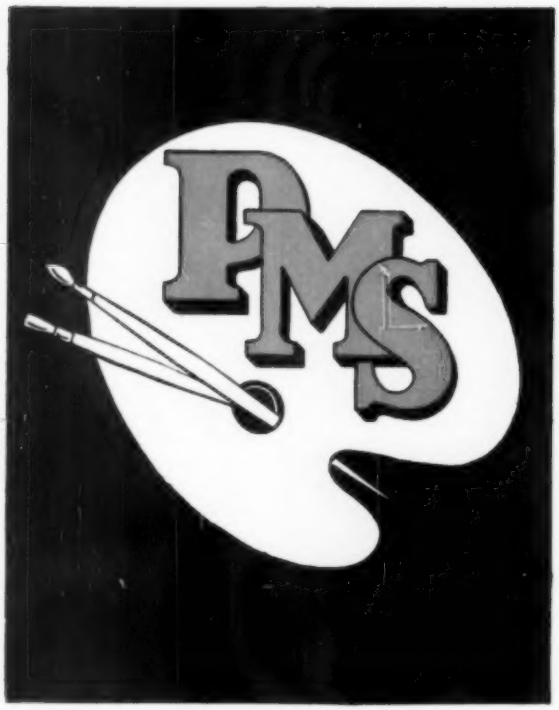

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tially absent is discussion of crystal structures with regard to chemical or structural type (metallic, ionic, molecular, high polymer, mineral, fibrous, laminar, etc.); the chemical significance of the results of crystallographic investigations is mentioned only in passing.

The author does not go very deeply into theory, but presents in a generally clear and competent way the minimum theory required in determining structures. Modern theoretical developments are briefly reviewed. A noteworthy feature of the book is the unusual amount of attention given to application of the theory in actual practice, as in determining space groups, solving the phase problem, and calculating electron density maps. A concluding chapter describes in considerable detail the actual determinations of several typical crystal structures. More by way of general interest than actual usefulness, there is a chapter describing most of the crystallographic computing techniques that have received serious attention, including some of little more than historical interest. Unhappily the most powerful computing methods, namely those employing punched cards and high-speed digital computers, receive only passing mention; this is illustrative of a lack of balance that seems to pervade the book.

The book is unusually well supplied with illustrations —perhaps too well in view of their contribution to the book's high cost, for although many are attractive and illuminating, many others (particularly those dealing with symmetry) are disappointing in regard to perspective and clarity, as well as in sharing with the text an unusually high content of errors.

The principal appeal of this book will be to the few thousand X-ray crystallographers whose field is structure determination, and to their students. However, its attractiveness for teaching will be largely offset by its high price.

David P. Shoemaker
Massachusetts Institute of Technology

HIGHER OXO ALCOHOLS

Lewis S. Hatch, John Wiley & Sons, Inc., New York 120 pages. $4.50.

This book presents an excellent review of the extensive patent literature on the oxo process. This short book, only 120 pages, contains a vast amount of information on the oxo process. It is excellently annotated with references to specific patents covering the various phases of the subject. Not only does the book give the essential details of the process but also covers many of the variables encountered with the particular compounds being reacted.

The oxo process is covered from every phase of its usage. The book also covers the various steps necessary in making the process successful and reducing it to practice. As added information, the book goes into the uses of the alcohols obtained from this process in industry today. It describes the method of manufacture of many of the derivitives of the oxo alcohols and in several cases gives actual laboratory preparations for the materials. The addition of these actual practical uses just adds spice to a very good book.

"Higher Oxo Alcohols" is very well written and easily read. The book would have only limited usage for the Plastics Engineers, but would be an excellent reference book for those people dealing with oxo alcohols who need a good bibliography.

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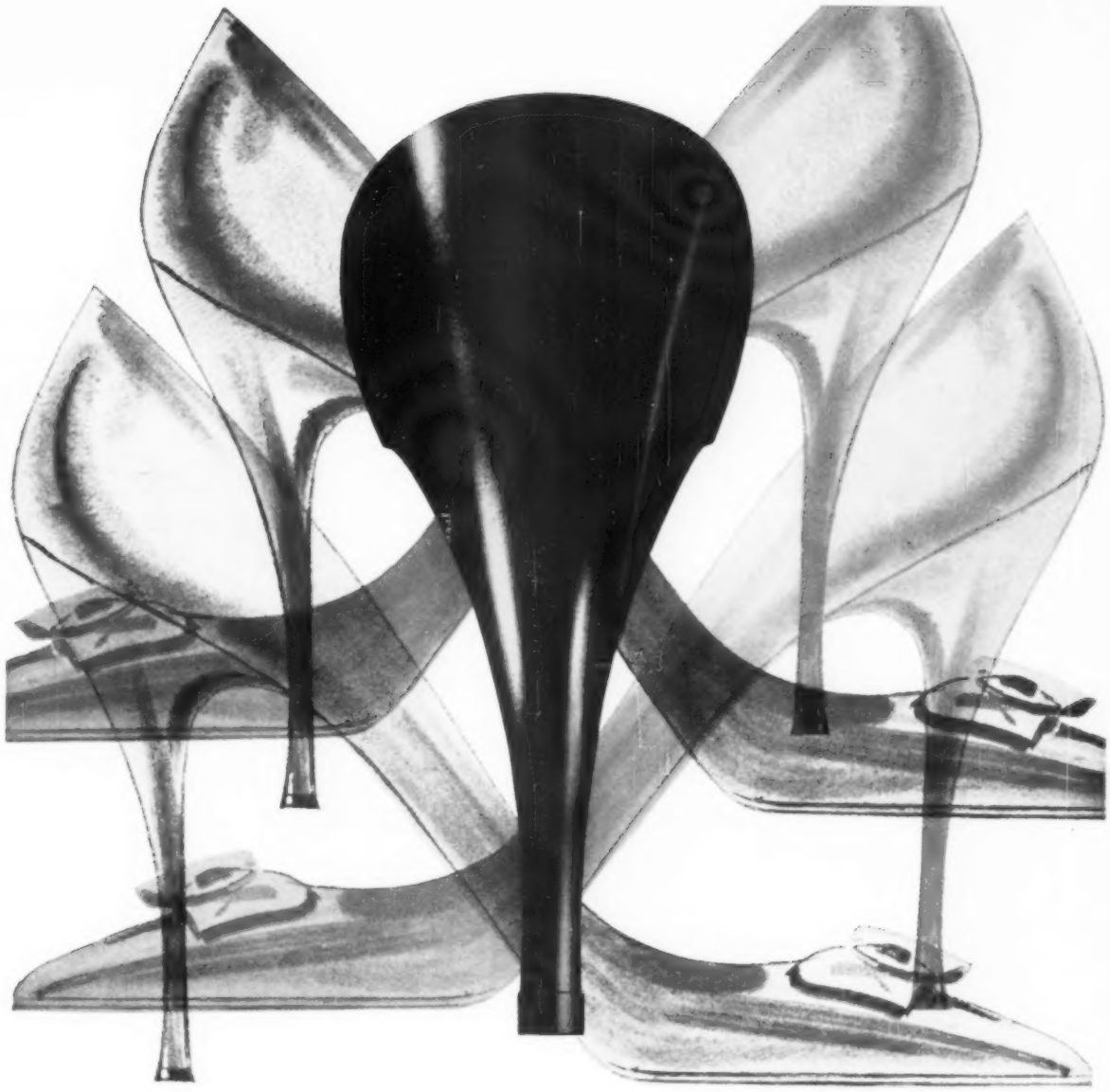

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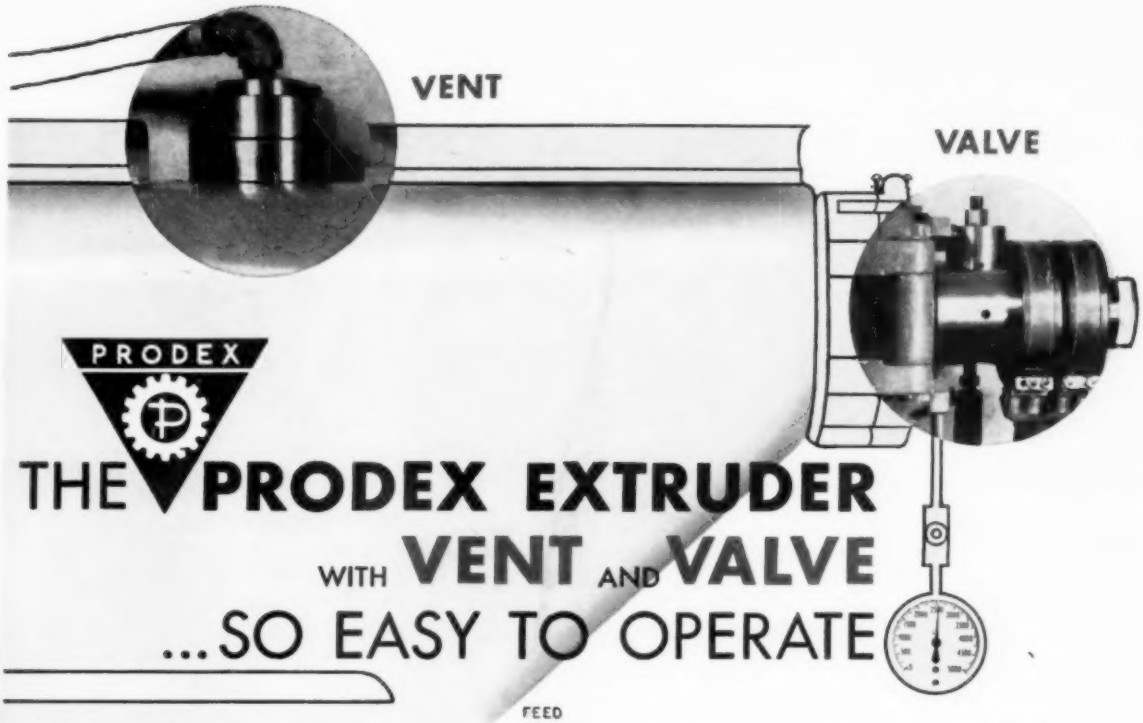

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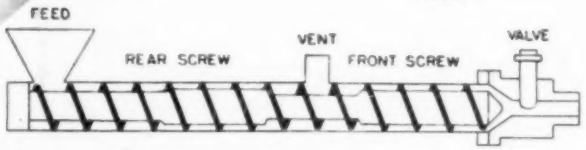

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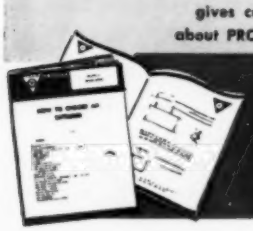

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